SOURCES, CYCLING, AND DEPOSITION OF ORGANIC MATTER IN NORTHERN NEWFOUNDLAND FJORDS AND BAYS

NATHANIEL EMIL OSTROM

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SOURCES, CYCLING, AND DEPOSITION OF ORGANIC MATTER IN NORTHERN NEWFOUNDLAND FJORDS AND BAYS

© Nathaniel Emil Ostrom, B.Sc.

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Abstract

An understanding of sources, cycling and deposition of organic matter in northern Newfoundland fjords and bays was gained through the use of stable carbon and nitrogen isotopic and elemental analyses. Seston from terrestrial stations was characterized by two groups: 1) stations which had a dominant influence of runoff had respective average $\delta^{15}N$, $\delta^{13}C$ and C/N compositions of 2.2°/oo, -25.5°/oo and 12.3 and 2) stations which appeared to be influenced by freshwater phytoplankton had average values of 5.1°/oo, -24.9°/oo and 8.1 for $\delta^{13}C$, $\delta^{15}N$, and C/N, respectively. A macroalgae endmember was defined by a $\delta^{15}N$, $\delta^{13}C$ and C/N of 4.6°/oo, -20.3°/oo and 9.2, respectively. Surface water seston which was not influenced by terrestrial detritus or macroalgae had average values of 8.2°/oo, -24.6°/oo, and 6.5 for $\delta^{15}N$, $\delta^{13}C$, and C/N, respectively, and was considered to be representative of a phytoplankton endmember.

The isotopic and elemental composition of POM isolated from the water column shifted in response to source, diagenesis and resuspension. Surficial sediments reflected contributions from both macroalgae and phytoplankton and showed little alteration by diagenesis. Degradation was evidenced by loss of organic matter with depth in all

sediment cores analyzed. With the exception of one location isotopic ratios were not altered by this process.

The retreat of the Wisconsinan ice sheet was recorded by variations in the geochemistry of sediment cores. The average $\delta^{15}N$, $\delta^{13}C$ and C/N of glacial till collected from the base of one core, 4.3°/oo, -25.3°/oo and 6.0, respectively, indicated a terrigenous origin. This till was a major contributor of organic matter to the lowermost 3 sedimentary units of that core. Shifts in $\delta^{15}N$ from 5.5 to 9.2 °/oo and $\delta^{13}C$ from -24.4 to -21.8°/oo above these units were related to changes in the relative contribution of phytoplankton and macroalgae. The isotopic and elemental composition of organic matter within Holocene sediments throughout all bays studied indicated a mixture of phytoplankton and macroalgae.

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INTRODUCTION

1. Purpose of study

Biological productivity and subsequent physical transport has led to the dispersal of organic compounds into the atmosphere, hydrosphere and lithosphere. During transport these compounds are subject to extensive alteration by biogeochemical reactions. Ultimately a portion of the organic matter produced is deposited and preserved in the sedimentary record. Once incorporated into the sediments organic material is progressively altered by diagenesis, catagenesis and metagenesis. Despite alteration in the water column and sediments, organic matter retains some chemical characteristics of the source material which can provide information about the productivity, climatology and transport processes that dominated the environment at the time of its deposition.

In this study the stable isotopic and elemental abundances of carbon and nitrogen were used to characterize sources and cycling of water column particulate and sedimentary organic matter in the waters of northern Newfoundland. With the isotope data dominant organic sources and their respective spatial distributions in the modern environment were established. This characterization provides a basis to evaluate changes in the relative

contribution and distribution of source organic material in Quaternary sediments as a consequence of climatic events.

The successful use of the isotope tracer technique requires the establishment of a firm basis for interpretation. This includes differentiation of organic matter sources in terms of their isotopic compositions. In addition the effects of alteration processes such as biogeochemical cycling and diagenesis must be evaluated.

2. Sources of organic matter

The isotopic composition of a sample is expressed in relation to a standard using per mil (°/oo) notation.

$$\delta^{13}C\ (°/oo) = \left[\frac{(^{13}C/^{12}C)_{sample}}{(^{13}C/^{12}C)_{standard}} - 1 \right] \times 1000$$

$$\delta^{15}N\ (°/oo) = \left[\frac{(^{15}N/^{14}N)_{sample}}{(^{15}N/^{14}N)_{standard}} - 1 \right] \times 1000$$

Carbon isotope compositions are reported relative to PDB, a Cretaceous belemnite from the Peedee formation of South Carolina. The standard for $\delta^{15}N$ is atmospheric nitrogen.

In the marine environment the primary contributors of organic matter are terrigenous and marine detritus. Aside from nearshore and deltaic environments, terrestrial

organic matter is not a significant contributor to the ocean (Eadie and Jeffrey, 1973; Gearing et al., 1977; Tan and Strain, 1979a; Cai et al., 1988). The marine component can be divided into phytoplankton and macroalgae. The carbon and nitrogen isotopic composition of these organic sources has been determined at many global locations, ranging from the equator to the arctic (Table 1, Fig. 1). A clear distinction can be seen between marine and terrestrial sources. The separation between phytoplankton and macroalgae may not be as clear. However, isotopic distinctions between these two sources of organic matter exist at some locations, for example in the Gulf of Maine and off Baffin Island (Table 1). This suggests the importance of defining these organic sources at a specific location. Other marine sources include seagrass and mangrove detritus, but these are not considered important to the Newfoundland system (Pulchan 1987, Troke 1987).

The isotopic composition of a primary producer is a function of the inorganic source and metabolic effects. Terrestrial plants and certain species of blue-green algae derive the majority of their nitrogen from the atmosphere and therefore have a $\delta^{15}N$ similar to nitrogen gas of 0°/oo (Hoering and Ford, 1960; Delwiche and Steyn, 1970; Macko et al., 1987a). The primary nitrogen source for marine algae is dissolved inorganic nitrogen in the form of nitrate or

ammonium. Reported $\delta^{15}N$ for oceanic nitrate and ammonium range between 6 and 10°/oo (Miyake and Wada, 1967; Cline and Kaplan, 1975; Liu, 1979). Upon assimilation, marine phytoplankton frequently have values similar to their inorganic nitrogen source (Table 1, Figures 2 and 3, Miyake and Wada, 1967; Wada 1980). However, phytoplankton may be isotopically depleted relative to the nutrient source as a consequence of fractionation, i.e. segregation of isotopes, during assimilation. Such effects result in a large range in $\delta^{15}N$ values of phytoplankton and will be discussed separately in section 3.

Atmospheric carbon dioxide, with a $\delta^{13}C$ of -7°/oo, and dissolved inorganic carbon, 0°/oo, are the inorganic carbon sources for land and marine plants respectively (Craig, 1953). Both marine and terrestrial plants become depleted in ^{13}C relative to their inorganic sources by approximately 20°/oo (Table 1, Fig. 2, Park and Epstein, 1961, Peters et al., 1978). Varying isotopic compositions among plants may result from different degrees of fractionation associated with pathways of inorganic carbon assimilation.

Such metabolic isotope effects are particularly prevalent in the terrestrial biosphere. The majority of terrestrial plants utilize the Calvin or C_3 photosynthetic pathway, and incorporates carbon dioxide through the enzyme ribose 1,5 bisphosphate carboxylase (RUBP). Plants using

this pathway have been reported to have carbon isotope values from -34 to -24°/oo (Smith and Epstein, 1971). A second method of carbon fixation is the Hatch-Slack or C_4 metabolic pathway which results in plant $\delta^{13}C$ values of -19 to -6°/oo (Smith and Epstein, 1971). Some species of marine phytoplankton have been observed to alternate between C_3 and C_4 metabolisms (Morris, 1980) but the isotopic effects of this have not been assessed.

Phytoplankton have been shown to vary in $\delta^{13}C$ between -31 to -19°/oo (Sackett et al., 1965; Gearing et al., 1984; and references therein). Variability in $\delta^{13}C$ of marine phytoplankton cannot be as clearly explained in terms of metabolic processes. Changes in temperature has been suggested as one cause for shifts in the $\delta^{13}C$ of phytoplankton (Sackett, 1964; Sackett et al., 1965; Deuser et al., 1968; Rodgers and Koons, 1969; Rodgers et al., 1972; Fontugne and Duplessy, 1981), though other evidence contradicts this (Calder and Parker, 1973; Fontugne and Duplessy, 1978; Rau et al., 1982; Gearing et al., 1984). Other factors which could cause variation in phytoplankton $\delta^{13}C$ include variation in species composition, changes in water masses, the $\delta^{13}C$ of dissolved inorganic carbon (DIC), the relative abundance of ^{13}C depleted lipids, the available CO_2 pool, salinity and decomposition within the water column (Parker, 1964; Degens, 1969; Deuser et al

1968; Deuser, 1970; Eadie and Jeffrey, 1973; Sackett et al., 1974; Wong and Sackett, 1978; Fontugne and Duplessy, 1978; Smith and Kroopnick, 1981; Gearing et al., 1984).

3. Cycling of organic matter in the sea

Studies characterizing the geochemistry of phytoplankton have done so by collection of particulate organic matter (POM). Two classes of POM are recognized on the basis of their residence time and size. Suspended POM or seston consists of small particles which have residence times on the order of several hundred years (McCave, 1975; Sackett, 1978). Seston is arbitrarily defined as the material retained on a filter with a pore size of 0.45 to 1μ (Entzeroth, 1982). The larger less abundant fraction, sinking POM, remains within the water column for days, weeks or less and consists primarily of fecal pellets, tests, and marine snow (McCave, 1975). Dissolved organic matter (DOM) is the fraction less than 0.45μ which passes through a seston filter.

Particulate organic matter in the sea is composed primarily of phytoplankton, zooplankton, bacteria and their decomposition products (Riley, 1970). Organic matter in sediments is derived from POM settling out of the water cclumn. Isotope studies usually assume that the organic matter preserved in sediments is a reflection of the

productivity in the overlying waters at the time of deposition. However, due to potential isotopic alteration processes subsequent to production, an understanding of the cycling and deposition of POM is essential to an interpretation of a sedimentary isotopic record (Figures 2 and 3).

In surface waters POM may undergo dissolution and form DOM. The $\delta^{13}C$ of DOM has been shown to be invariant with location and depth in the water column and is depleted in ^{13}C with respect to surface water seston as a consequence of biochemical oxidation or microbial utilization (Williams and Gordon, 1970; Ogura, 1972; Eadie and Jeffrey, 1973; Sigleo and Macko, 1985; Fig. 2 step 1). At the thermocline seston may be trapped, due to density stratification and be subjected to extensive biological utilization resulting in depleted $\delta^{13}C$ values (Jeffrey et al., 1983; Fig. 2 step 2). With increasing depth, seston can become slightly more enriched in ^{13}C via aggregation of DOM (Fig. 2 step 3) and dissolution of sinking POM (Fig. 2 step 4). In near bottom waters resuspension of sediments may cause a shift in the isotopic composition of seston towards sediment values (Tan and Strain, 1979a; Fig. 2 step 5).

Biological oxidation of suspended or sinking POM releases DIC depleted in ^{13}C. Therefore the $\delta^{13}C$ of DIC

may be used as an indicator of the extent of degradation of POM in waters. In some cases, the contribution of DIC from degradation can be quantitatively assessed (Kroopnick et al., 1972; Kroopnick, 1974; 1980). Other sources of DIC in waters can be distinguished and include input of organically-derived, ^{13}C-depleted riverine and soil DIC, and DIC from the dissolution of atmospheric carbon dioxide and calcium carbonate (Craig 1970; Kroopnick et al., 1972; Rau, 1978; Lee et al., 1987).

Information about productivity and biological respiration occurring in the water column can also be gained through $\delta^{13}C$ of DIC. In the euphotic zone ^{12}C is preferentially utilized in photosynthesis which results in an enrichment in ^{13}C in the remaining DIC pool. Nocturnal respiration releases DIC depleted in ^{13}C back into the water (Parker 1964; Smith and Kroopnick, 1981; Lee et al., 1987). The ^{13}C enriched DIC produced in areas of high productivity can, upon assimilation, result in isotopically enriched POM and sedimentary organic matter (Deuser, 1970; Tan and Strain, 1979a; 1979b; 1983).

The natural abundance of ^{15}N in POM results from the relative contribution of isotopically distinct organic sources, inorganic nitrogen source and subsequent cycling (Fig. 3). Some species of bacteria and blue green algae assimilate atmospheric nitrogen through nitrogen fixation.

This process involves a small or negligible fractionation which results in $\delta^{15}N$ values near 0°/oo for these primary producers (Hoering and Ford, 1960; Delwiche and Steyn, 1970; Macko et al., 1987a). Therefore, nitrogen fixation can influence the isotopic composition of POM in surface waters from in situ bacterial or blue green algae productivity (Wada and Hattori, 1976; Macko et al., 1984; Minigawa and Wada, 1986; Saino and Hattori, 1987; Fig. 3 step 1). Terrigenous organic matter is generally characterized by $\delta^{15}N$ values near 0°/oo, due to a predominance of nitrogen fixation in the terrestrial biosphere (Hoering and Ford, 1960; Delwiche and Steyn, 1970).

In environments not dominated by nitrogen fixation, ammonia is the preferred nitrogen source (Saino and Hattori, 1985). Inhibition of nitrate uptake may result from either high ammonia concentrations (Conway, 1977) or high light intensities (MacIsaac and Dugdale, 1972). When ammonia concentrations are low and uptake is the rate limiting step in photosynthesis, it has been suggested that preferential uptake of the light isotope does not occur (Saino and Hattori, 1985). The resulting POM would then be isotopically similar to the starting ammonia (Fig. 3 step 2). In contrast, if ammonia is abundant and not rate limiting a large fractionation occurs resulting in POM

depleted in ^{15}N relative to the starting ammonia (Wada and Hattori, 1978; Wada, 1980; Macko et al., 1987a; Fig. 3 step 3).

In the lower euphotic zone productivity can result from utilization of upwardly advecting nitrate. Often more nitrate is available than can be assimilated. In this situation nitrate is not rate limiting and a large fractionation results. During nitrate assimilation phytoplankton have been observed to be depleted in ^{15}N with respect to the initial nutrient sources. Values for lab and field studies show a 13 and 7°/oo decrease in $\delta^{15}N$, respectively (Wada and Hattori, 1978; Wada, 1980; Macko et al., 1987a; Fisher et al., 1988). Such fractionations result in a minimum in the $\delta^{15}N$ of seston (-1°/oo) in the lower euphotic zone (Fig. 3 step 4; Saino and Hattori, 1980; 1985; 1987).

Under anoxic conditions fractionation during denitrification results in the production of nitrogen gas depleted in ^{15}N relative to the remaining nitrate (Delwiche and Steyn, 1970; Cline and Kaplan, 1975; Wada, 1980; Fig. 3 step 5). The residual nitrate becomes enriched, reaching values as high as 18°/oo, relative to the average of 6°/oo for seawater nitrate (Miyake and Wada, 1967; Cline and Kaplan, 1975). If concentrations are sufficient to support productivity, this heavy nitrate becomes available to

phytoplankton upon advection into the overlying waters (Fig. 3 step 6). When nutrient concentrations are low and rate limiting, subsequent assimilation occurs without fractionation, resulting in seston with an isotopic composition similar to the residual nitrate (Sigleo and Macko, 1985; Fig. 3 step 7).

Nitrification can occur in oxic waters. A large fractionation associated with this process results in the production of nitrate depleted in ^{15}N, with the remaining ammonia becoming enriched, potentially reaching $\delta^{15}N$ values as high as 20°/oo or greater (Delwiche and Steyn, 1970; Mariotti et al., 1984; Fig. 3 step 8). Assimilation of the residual ammonia by phytoplankton under rate limiting conditions results in seston with a similar isotope value to the ammonia (Mariotti et al., 1984; Fig. 3 step 9).

Degradation of seston in the lower euphotic zone causes enrichment in ^{15}N in the suspended load (Saino and Hattori, 1980; 1985; 1987; Fig. 3 step 10). Enrichments in suspended or sinking POM can also result from a contribution of zooplankton detritus enriched in ^{15}N due to a trophic level fractionation effect of 3°/oo (Fig. 3 step 11; DeNiro and Epstein, 1981; Macko et al., 1982). It has been suggested that in some cases sinking POM produced in the euphotic zone is isotopically heavier than suspended POM due to a contribution of fecal matter enriched in ^{15}N

(Checkley and Entzeroth, 1985; Altabet, 1988; Fig. 3 step 12). Dissolution of sinking POM, fractionation during deamnation reactions and/or oxidative degradation in deeper waters results in ^{15}N enriched seston (Saino and Hattori, 1987; Altabet, 1988; Fig. 3 step 13). These mechanisms explain the average observed enrichment of up to 6°/oo in lower water seston relative to surface waters.

The major source of organic matter in sediments is from primary productivity occurring in the overlying surface waters. However, significant isotopic differences between sedimentary and particulate organic matter have been found. This may be related to the fraction of POM analyzed or preserved. In some cases sinking and suspended POM has been found to be isotopically similar to sedimentary organic matter (Entzeroth, 1982; Wada et al., 1987b; Libes and Deuser, 1988; Cifuentes et al., 1988). Differences in $\delta^{13}C$ between POM and sediments may be accounted for by a greater relative contribution of isotopically distinct diatom or nanoplankton detritus in productivity or preservation (Gearing et al., 1984). Isotopic fractionation at the sediment water interface has been suggested as an additional cause of sediment and POM differences (Eadie and Jeffrey, 1973; Libes and Deuser, 1988).

In estuarine waters the isotopic composition of POM

can vary considerably on a seasonal basis. Yearly variation in the $\delta^{15}N$ of POM ranges between 7 and 20°/oo (Mariotti et al., 1984; Cifuentes et al., 1988; Gearing et al., 1988). Seasonal changes in the $\delta^{13}C$ of POM can fluctuate as much as 10°/oo (Gearing et al., 1984; Cifuentes et al., 1988). In oceanic waters of the Sargasso Sea seasonal nitrogen isotopic variation of sinking POM was correlated with the carbon flux (Altabet and Deuser, 1985). This suggests that the isotopic composition of sedimentary organic matter may more strongly reflect the $\delta^{15}N$ and $\delta^{13}C$ of POM during maximum flux periods as would occur during a spring bloom (Cifuentes et al., 1988).

4. Carbon and nitrogen isotopic and elemental abundances as tracers of organic matter in sediments

The determination of the $\delta^{13}C$ of sedimentary organic matter as a basis for separating marine and terrestrial sources has been well established. With the exception of large river deltas, terrestrial organic matter is not extensively transported onto the continental shelves (Sackett and Thompson, 1963; Sackett, 1964; Hunt, 1970; Shultz and Calder, 1976; Gearing et al., 1977; Hedges and Parker, 1976; Tan and Strain, 1979b). In several estuaries a terrestrial influence on sediments was not carried beyond 10 miles inland from the river mouth (Hunt, 1970). However,

near large river deltas, terrigenous organic matter may be carried as much as 100km offshore (Kennicutt et al., 1987). In addition to deltaic environments, terrestrial detritus may be transported offshore by ice rafting in high latitude areas (Gearing et al., 1977; Sackett, 1986b).

Several studies in the Gulf of Mexico have shown a terrestrial influence near the bottom of piston cores (Sackett, 1964; Parker et al., 1972; Newman et al., 1973). Upon lowering of the sea level during glacial periods terrestrial organic matter was deposited onto the continental slope and abyssal plain (Parker et al., 1972; Newman et al., 1973). In this way $\delta^{13}C$ becomes a tool for identifying climatically influenced depositional events.

In a similar manner as $\delta^{13}C$, stable nitrogen isotopes have proven useful in resolving marine and terrigenous sources of organic matter in sediments (Peters et al., 1978; Sweeney and Kaplan, 1980b; Macko, 1981; 1983). As a consequence of distinct metabolic pathways and differing inorganic nitrogen sources, terrestrial and marine plants can be distinguished on the basis of $\delta^{15}N$ values. Furthermore, mixing models based on nitrogen isotope abundances can be used to predict the relative contributions of marine and terrestrial detritus to sediments (Peters et al., 1978; Sweeney and Kaplan, 1980b; Macko, 1983).

Sedimentary $\delta^{15}N$ values have been useful in recognizing other sources of organic matter. These include the ability to trace sewage, kelp, seagrass, mangrove and marsh detritus (Sweeney and Kaplan, 1980a; Sweeney et al., 1980; Macko, 1981; 1983; Macko et al 1987b; Pulchan, 1987; Troke 1987). In addition, a distinction can be made between sediments associated with nitrogen fixing and nitrate assimilating phytoplankton (Stuermer et al., 1978; Macko et al., 1984). This technique has been used to recognize the predominance of nitrogen fixation in the Cretaceous (Rau et al., 1987).

Changes in oceanic productivity may also be recognized by the nitrogen isotopic signature within sediments. During periods of low productivity complete assimilation of available nitrate may not be possible. Nitrate uptake under these conditions is not rate limiting and results in phytoplankton depleted in ^{15}N. When nitrate is rate limiting, as would occur during high productivity, no net fractionation occurs and phytoplankton isotopically resemble the available nitrate (Wada and Hattori, 1978; Wada 1980). On this basis, large scale productivity changes have been recognized in middle Miocene to Recent sediments from the Baffin Bay (Macko, 1988).

Carbon to nitrogen ratios provide another tool for assessing the origins of sedimentary organic matter.

Marine phytoplankton are abundant in nitrogen-rich proteins and therefore have a low C/N of approximately 6 (Muller, 1977). Terrestrial plants have a much lower protein content, and therefore have a high C/N with values between 14 and 30 (Godell, 1972).

Although C/N frequently correlates with $\delta^{13}C$ as source indicators of organic matter in sediments, they are considered less reliable than carbon isotope values (Tan and Strain, 1979b; LaZerte, 1983; Kennicutt et al., 1987). The greater uncertainty in this method is a consequence of the wide variation in the terrestrial endmember (Tan and Strain, 1979b), or the magnitude of error in measuring both elemental carbon and nitrogen (Waples and Sloan, 1980).

In addition, marine and terrestrial distinctions are obscured by alteration of C/N in the water column and sediments. A preferential loss of more labile nitrogen rich components during decomposition results in higher C/N and can cause overlap of the terrestrial and marine endmembers (Peters et al., 1978). Sedimentary C/N lower than 3, the value for pure protein, have been observed and are primarily caused by the presence of inorganic ammonia that is either dissolved or bound in clays (Muller, 1977; Meyers and Keswani, 1984). Absorption in clays of organic compounds with low C/N, such as amino acids, may also yield low C/N in sediments (Muller, 1977; Pillon et al., 1986).

By using C/N in conjunction with isotopic analyses sources of organic matter and diagenetic effects may be better defined than by use of either technique alone.

5. Diagenesis and isotopic integrity

Diagenesis in sediments has been recognized by depletions of organic carbon and nitrogen with depth in a sedimentary sequence (Montani et al.,1980; Waples and Sloan, 1980). Some studies have concluded that diagenesis does not significantly alter the isotopic composition or organic matter in sediments (Sackett, 1964; Sweeney et al., 1980; Arthur et al., 1985; Dean et al., 1986; Schidlowski, 1987). However, changes in isotopic values for both carbon and nitrogen down core have been attributed to diagenetic alterations (Sackett, 1964; Macko, 1981; Macko et al., 1987b). Enrichments in ^{13}C can result from loss of isotopically light lipid material or diagenesis under anaerobic conditions (Sackett, 1964; Behrens and Frishman, 1971; Macko, 1981). Loss of ^{13}C enriched proteins and carbohydrates or loss of terminal isotopically heavy carboxylic acid groups results in lower $\delta^{13}C$ values (Degens et al., 1968b; Brown et al., 1972; Macko, 1981; Spiker and Hatcher, 1984; 1987). Enrichments in ^{15}N in sediments have been attributed to loss of more easily hydrolyzable nitrogen compounds (Macko, 1981; Macko et al., 1987b).

Several studies have been conducted to investigate isotopic changes during decomposition. In phytoplankton decomposition studies, no significant change in $\delta^{13}C$ was observed (Gearing et al., 1984). However, decomposition has been shown to produce changes in the $\delta^{15}N$ of marine detritus as large as 10°/oo (Wada, 1980; Zieman et al., 1984). These findings suggest that microbial alteration cannot be ignored when evaluating the isotopic signal preserved in sediments.

6. Study site: northern Newfoundland fjords and bays

The Newfoundland continental shelf is characterized by central basins and fjords with depths of 200 to 400m (Scott et al., 1984). These basins were probably excavated from the underlying bedrock during pre-late Wisconsinan glacial advances and are currently covered primarily by glaciomarine sediments (Dale 1979, Dale and Haworth, 1979). Wave or tidal reworking of shallower shelf sediments has resulted in redeposition of finer sediments in the basins with the coarser fractions remaining on the banks (Scott et al., 1984). In nearshore areas, fluvial input and offshore transport of terrestrial debris has contributed to post-glacial sediment deposition (Dale, 1979).

Micropaleontological evidence of sediments off northern and eastern Newfoundland has revealed a sequence

of Quaternary climatic events. Water temperatures of 0 to 3°C, similar to the present inner Labrador current, dominated throughout most of the Wisconsinan ice age. In the mid-Wisconsinan an interstadial is suggested by moderately warmer outer Labrador current water temperatures of 2 to 4°C (Scott et al., 1984; Miller, 1987). Retreat of the late Wisconsinan ice sheet was concurrent with water temperatures similar to the interstadial and glacial ice margin conditions that may have been almost fluvial at times (Mudie and Guilbault, 1982; Scott et al., 1984; Miller et al., 1985; Miller, 1987). Complete deglaciation of the land mass took place prior to 12,000 yr BP (Blake, 1983; Macpherson, 1988).

Outer Labrador current conditions dominated the northern Newfoundland continental shelf in the early Holocene with the exception of a brief incursion of inner Labrador current water at the Holocene-Pleistocene boundary. Development of the Labrador current may have occurred at this time. In the mid-Holocene water temperatures similar to the present outer Labrador current continued to dominate though a brief warm interval from 5000 to 7000 yr BP has been suggested (Scott et al., 1984; Miller et al., 1985; Miller, 1987). Separation of the Labrador current into inner and outer currents occurred in the late Holocene (Scott et al., 1984). Inner Labrador

current waters have dominated the northern Newfoundland shelf since that time, although Gulf stream waters may have influenced water temperatures off Bonavista Bay, Newfoundland (Scott et al., 1984; MacNeil, 1986; Miller, 1987).

Organic geochemical studies in Newfoundland bays have been useful in tracing sources of organic matter and climatic events. Deposition of terrestrially derived glacial till in Bay D'Espoir was characterized through $\delta^{15}N$ and $\delta^{13}C$ analysis (Pulchan, 1987). The organic component of Holocene sediments was characterized as having a marine macroalgae origin, indicative of interglacial conditions (Pulchan, 1987; Troke, 1987). Isotope studies of modern organic matter have recognized the predominance of phytoplankton as a contributor to seston in Bay D'Espoir and Fortune bay (Dickson, 1986), and deposition of terrestrial detritus offshore, resulting from paper mill effluent in Bay of Isles (Tan and Strain, 1979b).

7. Synopsis

Carbon and nitrogen isotope and elemental ratios have been widely recognized as tracers of organic and inorganic sources in the natural environment. Tracing with these methods can be problematic due to large variations within endmembers and the effects of diagenesis. This study

involved a carbon and nitrogen isotopic and elemental evaluation of sources, distribution and preservation of organic matter in the fjords and bays of northern Newfoundland (Figures 4-11). Sources were collected and analyzed to define endmember geochemical compositions. Distributions of these sources in the modern and ancient environment was assessed by comparisons of several bays and transects from bay heads to the offshore. The effects of diagenesis were determined by methodical comparisons of surface samples with those deeper in the water column or sediments.

Materials and Methods

1. Sample collection and preparation

Marine water column and sediment samples were taken along the north and east coasts of Newfoundland in the summers of 1986 and 1987, during four research cruises aboard the RV Wilfred Templeman, CSS Dawson and CSS Baffin. Waters from riverine drainages were obtained at road side stations (Fig. 4-1, Appendix 1). All samples were analyzed for $\delta^{13}C$, $\delta^{15}N$, and carbon and nitrogen abundances to characterize organic matter sources and to assess the geochemical effects of diagenesis. The $\delta^{13}C$ of DIC and dissolved oxygen concentrations for some stations were determined to provide additional data on biogeochemical processes occurring in the water column (Appendices 2 and 3). Sediment color was indicated by Munsell color notation in core descriptions to assist in correlating sedimentary units among cores (Kollmorgen Corporation, 1975). Grain-size analyses (Folk, 1980) were done on one core to assist in characterizing the depositional environment (Appendix 4).

Surficial sediments were collected with a $0.25m^2$ Van Veen grab sampler. Once the sediment was recovered two samples were taken, one from the upper oxygenated layer and

another from a depth of 3cm. Gravity and piston cores were used to penetrate deeper sediments, with a maximum recovery of 5.5m. Cores were refrigerated (3°C) prior to removal of sediment samples at 10 or 20cm intervals within one month of core collection. A comparison of samples taken three weeks after storage at 3°C and those taken after one and one-half years at room temperature was made to assess the effects of storage on sedimentary organic isotopic and elemental data.

Surface, middle and bottom waters were obtained by lowering 5L Niskin bottles to 5m, 100m and 5m above bottom, respectively. An aliquot of 25ml was retained for analysis of DIC. Excess mercuric chloride was added to inhibit respiration. An additional 300ml of water was reserved for determination of dissolved oxygen. Oxygen concentrations were determined, within a few hours of collection, by Winkler titration using phenylarsine oxide in place of thiosulfate (Hach Chemical). Seston was isolated from the remaining 5 to 10L of water by filtration through pre-ashed 47μ GF/C glass fiber filters. All filters were rinsed with at least 300ml of distilled water to remove salts and acidified to remove carbonate (30% HCl).

2. Isotopic analysis

In preparation for isotopic analysis sediments were

freeze dried, acidified (30% HCl), dried and ground into a fine powder. Combustion of organic matter was performed using a modified Dumas method (Macko, 1981). The surficial layer of the POM filter or 200 to 400mg of sediment was placed in an ashed quartz tube. Precombusted copper oxide (BDH Chemical) and pure copper (Alpha Resources Inc.) was added in a ratio of 5:1:1 to the sediment or filter. Evacuated samples were heated to 850°C and allowed to cool gradually overnight to prevent formation of carbon monoxide and nitrous oxides.

Carbon dioxide and nitrogen gas were separated cryogenically from the combustion products on a vacuum line. Purified carbon dioxide and nitrogen gas samples were analyzed for their isotopic compositions on either a VG 903E or Prism triple collector stable isotope ratio mass spectrometer. All samples were analyzed by comparison to laboratory gas standards which were calibrated with respect to NBS standards. Isotope ratios are reported in per mil notation relative to PDB and atmospheric nitrogen standards for carbon and nitrogen, respectively.

Abundance measurements for nitrogen gas samples were determined using a calibrated volume within the mass spectrometer. The ion beam produced is proportional to the pressure of the gas. Carbon abundances were determined on a calibrated manometer during cryogenic gas separation.

3. DIC extraction

Extraction of DIC from water samples was performed by cryogenic purification on a vacuum line. A weighed sample of approximately 20ml was acidified under vacuum with phosphoric acid to release carbon dioxide gas. Water vapor was separated from the evolved carbon dioxide in a cooled U-trap (-60°C). In-line diffusion and toepler pumps were used to transfer the carbon dioxide to a calibrated manometer for determination of DIC concentration.

4. Sediment grain-size analysis

The relative abundances of sand, silt and clay fractions were determined for core SB3, using the method of Folk (1980). Carbonate content was qualitatively assessed by observing the degree of effervescence during acidification with 30% HCl. Subsamples of 20g were taken from this core at 25cm intervals. Samples were dried, weighed and washed through a 63um sieve. The portion that remained on the sieve represented the sand fraction. The wash passing through the sieve was added to a 1L settling cylinder. Twenty ml of a 0.1 molar solution of sodium hexametaphosphate was added as a dispersant and the wash was diluted to 1L. The settling column was vigorously stirred to evenly distribute the size fractions and 20ml aliquots were removed by pipet at specific time and depth

intervals (Table 1). Aliquots were dried (150°C) and weighed. All final weights were corrected for sodium hexametaphosphate contributions. Silt and clay abundances were calculated from the 20 second and 2 hour aliquots, respectively.

Results

The distribution of source organic material in the Newfoundland bays was revealed through determination of the isotopic abundances in riverine and marine seston and surficial sediment samples. Samples of seston and DIC taken at various depths were used to evaluate diagenesis within the water column. A comparison of surficial sediments with samples taken at 3cm was made to assess alteration processes within upper sediments. This data provided a basis to evaluate the isotopic signature preserved in Quaternary sediments.

1. Analysis of organic matter sources

The C/N, $\delta^{13}C$ and $\delta^{15}N$ of several species of marine plants, POM obtained from phytoplankton tows, river seston and a terrestrial sediment were analyzed to characterize their organic geochemical compositions (Tables 3, 4). Considerable variability exists in isotopic and elemental compositions among the various species of algae. The respective $\delta^{15}N$ and $\delta^{13}C$ values for the kelps range from 3.9 to 7.7°/oo and -21.0 to -13.0°/oo. Ratios of carbon to nitrogen exhibit a wide range of 7.78 to 27.79.

A large range of values in isotopic composition and C/N are also observed within a single plant leaf. Though

similar in $\delta^{15}N$, the $\delta^{13}C$ and C/N of a Laminaria digitata leaf are greater than the stalk by 3.6°/oo and 11, respectively (Table 3). The range of values for 15 samples taken within a single blade of Laminaria solidungula is 8.26 for C/N, 3.1°/oo for $\delta^{13}C$ and 7.3°/oo for $\delta^{15}N$ (Figure 12). The central portion of the leaf has a relatively low $\delta^{15}N$ of 3.3°/oo, a high $\delta^{13}C$ of -22.2°/oo, and a high C/N of 14.14 when compared to other parts of the blade. The holdfast has a high $\delta^{15}N$, a very low $\delta^{13}C$ value and a low C/N.

The marine angiosperm, Zostera marina, had a $\delta^{15}N$ of 4.8°/oo, a C/N of 17.36 and is enriched by 3°/oo relative to the nearest $\delta^{13}C$ value of the kelps (Table 3). Filamentous particulate matter collected from the plankton tows, with a $\delta^{13}C$ of -21.5°/oo and a $\delta^{15}N$ greater than 9°/oo, is at least 1.5°/oo more enriched in ^{15}N and slightly more depleted in ^{13}C than the algae. The low C/N of plankton tow material relative to other organic matter sources reflects the nitrogen-rich composition (Table 3).

Terrigenous organic matter from rivers is characterized by low $\delta^{13}C$ values in relation to the other organic matter sources. Brook sediment and river seston is depleted in ^{13}C by 6°/oo and 4°/oo, respectively, in comparison to the plankton tows (Tables 3, 4). The nitrogen isotopic composition of terrestrial seston ranges

from 1.6 to 6.5°/oo and overlapped 1.5°/oo with the kelp values. Seston from the Exploits River has the lowest $\delta^{15}N$. Most elemental carbon to nitrogen ratios for terrigenous samples are lower than those of the algae. The highest riverine C/N value is observed in the Exploits River.

Marine surface water seston was characterized by average $\delta^{15}N$ and $\delta^{13}C$ values of 7.4 and -24.3°/oo, respectively (Table 5). Surface, middle and bottom waters, are similar in average $\delta^{13}C$ (Table 5). The $\delta^{15}N$ of bottom waters is enriched by 1.6°/oo relative to the surface (Table 4). The range of isotope values for all seston samples is 1.5 to 16.8°/oo for $\delta^{15}N$, -21.0 to -30°/oo for $\delta^{13}C$ (Table 6). The range of C/N is from 1.8 to 27.4 and increase within the water column in the order middle < surface < bottom (Table 5). The average concentrations of total suspended matter and its organic carbon and nitrogen increase in the order middle < surface < bottom (Table 7).

Isotopic and elemental data for seston samples show considerable variability among stations and cruises (Table 6). Despite this scatter, distinct trends between spring and fall sampling and with depth can be discerned. In May, surface water seston commonly has low $\delta^{15}N$ and high C/N values as compared to collections in August and November. This difference is particularly evident in Exploits,

Bonavista and Trinity Bays.

The $\delta^{15}N$ of seston from middle waters exhibit two patterns of variation. At the majority of stations surface and bottom waters are isotopically similar to each other but distinct from middle water samples. This trend is particularly evident at EX4 in May and GB3, WB1, and ND2 in August (Figures 13 and 14). At other locations, such as EX6 in August and ND2 in May, $\delta^{15}N$ values increase with depth (Fig. 15).

Frequently, the isotopic composition of seston from bottom waters is shifted from that of middle waters in the direction of the $\delta^{15}N$ and $\delta^{13}C$ of the underlying sediments (Figures 14 and 16). In addition, bottom water seston at nearly all stations has greater organic and total suspended matter concentrations than samples from the overlying waters (Table 6).

The average $\delta^{13}C$ of DIC values for bottom and middle waters are depleted by 3 and 1.5°/oo, respectively, relative to the surface water (Table 8, Figure 17). Concentrations of DIC in most samples collected below 22m are greater than those taken at the surface (Table 8, Figure 18). In addition there is no significant relationship between $\delta^{13}C$ of DIC and the concentration of dissolved oxygen ($R < 0.15$).

2. Surficial sedimentary organic matter

The average nitrogen isotopic composition of surficial sedimentary organic matter obtained from surficial sediments 7.6°/oo, is nearly identical to that of surface water seston (Tables 5 and 9, Figure 19). The average $\delta^{13}C$ for surface sediments, -21.8°/oo, is enriched by 2.5°/oo relative to surface water seston, and is similar to the values for POM from the plankton tows (Tables 3, 5 and 9, Figure 20). Ratios of carbon to nitrogen for grab samples average 6.7. This value is less than that of marine seston and greater than that of tow POM (Tables 3, 5 and 9). Sediments taken from the surface and those at a depth of 3cm are nearly identical in average isotopic and elemental compositions (Table 9). In all bays abundances of carbon and nitrogen are lower in offshore stations than in the nearshore (Table 10).

If Exploits Bay and the nearshore station in White Bay are excluded from the surface sediment data set the variation in $\delta^{13}C$ is only 1°/oo. The lowest $\delta^{15}N$ and $\delta^{13}C$ and the highest levels of organic carbon and nitrogen are observed in nearshore stations of Exploits Bay (Table 10). Increasing enrichments in ^{15}N and ^{13}C are observed with distance from the head in Exploits Bay, though not in a similar transect within Conception Bay (Figures 21 and 22). Similarly, Halls and White Bays exhibit depletions in ^{13}C

within nearshore stations relative to the offshore (Table 10).

3. Decomposition experiment

A comparison of samples taken 3 weeks after storage at 3°C and those taken after 1 1/2 years at room temperature is shown in Tables 11 and 12. Only minor differences in carbon and nitrogen isotopic and elemental values exist between the two sets of data. Carbon abundances and C/N values are greater in the 1 1/2 year data set. The range of $\delta^{15}N$ values in the 1 1/2 year samples is greater by 0.9°/oo than the 3 week samples.

4. Sediment cores

4a. Core SB3

Core SB3 was collected from within the Notre Dame Basin (Fig. 4) and has a total length of 525cm. Within this core five sedimentary units are identified (Fig 23). Based on sediment descriptions and lithology these units appear to correlate with specific units described by previous work in this area (Dale and Haworth, 1979; Dale, 1979; Mudie and Guilbault, 1982; Scott et al., 1984; MacNeil, 1986 and Macpherson, 1988). These units are thought to represent a complete sequence of events since the mid-Wisconsinan (Dale, 1979; Mudie and Guilbault, 1982;

Scott et al., 1984). Core SB3 is the only core in this study which penetrated to unit 5. Therefore, core SB3 is considered to represent the most complete sequence of climatic events of all the cores collected in this study.

Unit 5 (526 to 505cm) consists of a poorly sorted red (10R 4/6) mud which is greater than 50% sand (Fig. 24). Previous studies have indicated that this unit is composed of glacial marine till (Dale, 1979 and Scott et al., 1984). The $\delta^{13}C$, -25.5°/oo, and elemental abundances in unit 5 are the lowest of any unit in this core (Figures 25 and 26). Nitrogen isotope values of 4 to 5°/oo are also lower than the majority of samples within this core (Fig. 25). Carbon to nitrogen ratios are between 3 and 8 which is typical of the entire core (Fig. 27).

Within unit 4 (505 to 443cm) the sediment is weak red (10R 5/4) in color and more stratified than in unit 5. The sand content ranges between 20 and 40% and is at least 10% lower than that of unit 5 Organic abundances and nitrogen isotope values in unit 4 are only slightly greater than in unit 5, however $\delta^{13}C$ values are nearly 2°/oo greater.

Unit 3 extends from 443 and 395 cm. Within this unit, between 443 and 395cm, several distinct olive gray (5Y 4/2) laminations, identified as diatomaceous muds (A. Aksu, Dept. of Earth Sciences, Memorial University of Newfoundland, personal communication), are visible against

the reddish gray (10R 5/1) mud which comprises most of this unit. The lowermost samples within this unit are characterized by $\delta^{15}N$ and $\delta^{13}C$ values 2°/oo greater than in unit 5. A diatomaceous lamination at 412cm is isotopically similar to unit 5 with a very low $\delta^{15}N$ value of 4.1°/oo and a $\delta^{13}C$ of -25.3°/oo. In addition a high C/N, of 12.4, occurs in close association with this lamination (Figures 23 and 27). Organic carbon and nitrogen concentrations for the entire unit are greater than that of unit 4 with maximum abundances of 0.66 and 0.14%, respectively. The sand component increases with depth reaching a maximum of 4.5%.

Unit 2 (395 to 55cm) is divided into 3 subunits based on sediment coloration and carbonate content (Dale 1979 and Mudie and Guilbault, 1982). The lowermost subunit, 2c, extends from 395 to 177cm and is further divided into four zones based on the isotope data and sediment coloration (Fig. 23). The entire subunit is characterized by a relatively moderate carbonate content.

With the exception of a reddish gray (10Y 5/2) color in zone 2, between 256 and 195cm, an olive gray (5Y 5/2) to gray (5Y 5/1) sediment coloration dominates most of subunit 2c. Zones 2 and 3 contain less than 3% sand whereas units 1 and 4 have greater than 13%. Carbon and nitrogen isotopes increased from minimum values of -23 and 6°/oo,

respectively, in zone 4 to maximum values of -21.8 and 9.2°/oo, respectively, in zone 3. Low values are again evident in zone 1. Abundances of organic carbon and nitrogen vary in a similar manner with maximum values of 0.89 and 0.22%, respectively, in zone 3 and minimums in zones 1 and 4.

The sediment in subunit 2b, between 177 and 163cm, has a distinctive grayish brown (2.5Y 5/2) coloration and a relatively high carbonate content. Only one sample was taken from within this subunit and this is characterized by a $\delta^{15}N$ of 6.1°/oo and a depleted $\delta^{13}C$ of -24.9°/oo. An unusually low C/N of 1.7 is found for this sample as well as low abundances of organic carbon and nitrogen.

Subunit 2a extended to 55cm and has an olive gray (5Y 4/2) coloration with slight black mottling and a moderate carbonate content. Abundances of sand decrease from a maximum of 30% near subunit 2b to a minimum of 3% near unit 1. Silt concentrations are constant at approximately 50%. Organic abundances increase steadily throughout this subunit with the greatest values at the core top of 1.13% for carbon and 0.32% for nitrogen. Carbon isotope values are low and slightly higher than in subunit 2b. Slight enrichments in ^{15}N in subunit 2a relative to 2b are evident.

A dark olive gray (5Y 3/2) coloration with black

mottling dominates in unit 1. Isotope values are greater in $\delta^{13}C$ than in subunit 2a, with a maximum of -22.5°/oo, though similar in $\delta^{15}N$. In addition, sand and silt concentrations, 7 and 64%, respectively, are similar to the uppermost sample in subunit 2a.

4b. Core WB1

This core was collected 10km from the head of White Bay (Fig. 4). The entire length of core WB1, 531cm, consists of an olive gray (5Y 4/2) mud with varying amounts of heavy black mottling. This suggests that only unit 1 is represented. A steady increase in $\delta^{15}N$ values is observed from 7°/oo near the top to 9°/oo at the core bottom (Fig. 28). The average $\delta^{13}C$ value between 220 to 314cm, 24.6°/oo, is 1.7°/oo more depleted than the average for sediment below 344cm (Fig. 28). Above 220cm carbon values increase to a maximum of -22.0°/oo at 20cm. The upper 20cm are slightly depleted relative to those below.

Organic carbon and nitrogen abundances generally increase up core and range from 0.99 to 4.83% and 0.13 to 0.49%, respectively (Fig. 29). The uppermost few samples show slight reductions in organic nitrogen. Throughout the core most C/N values range between 6 and 12 (Fig. 30). However, the C/N of the sample at the core top, 19, greatly exceeds this range.

4c. Core WB7

Core WB7 was collected 71km from the head of White Bay with a total recovery of 430cm (Fig. 4). The sediment from core WB7 consists of an olive (5Y 4/4) to dark olive gray (5Y 4/2) mud with moderate black mottling throughout its entire length. Based on these sediment characteristics this core is interpreted as consisting entirely of unit 1.

A steady increase in $\delta^{13}C$ up core is apparent with depleted values near -25°/oo at the core bottom and -21°/oo at the top (Fig. 31). The $\delta^{15}N$ above 390cm range between 6.4 to 8.1°/oo (Fig. 31). Sediments below 400cm are enriched in ^{15}N by as much as 1.6°/oo relative to this range.

Throughout the lower half of the core, elemental abundances are near 0.5% for carbon and 0.1% for nitrogen (Fig. 32). Between 203 and 153cm elemental abundances increase then remain nearly constant to 0cm. Maximum concentrations of carbon and nitrogen for the core are 2.78 and 0.60%, respectively. Most C/N values range between 4 and 8 and no trend with depth is observed (Fig. 33).

4d. Core GB2

Core GB2 was collected 7km from the head of Green Bay, a fjord that opens into Notre Dame Bay (Fig. 4). Total

sediment recovery was 321cm. The upper 44cm of core GB2 consists of a dark olive gray (5Y 4/2) mud characteristic of unit 1. Beginning at 44cm to the core bottom the sediment changes from an olive gray (5Y 4/2) to dark gray (5Y 4/1) mud with moderate black mottling. This interval has a moderate level of carbonate.

Nitrogen isotope values are constant throughout the core and range between 7.0 and 8.5°/oo (Fig. 34). A change in $\delta^{13}C$ is evident between samples below 44cm which have values near -22°/oo and those above which are approximately -21°/oo (Fig. 34). In addition elemental abundances are different between these depths (Fig. 35). Concentrations of carbon and nitrogen below 200cm, 0.7 and 0.1% respectively, are constant and more enriched than those of the sediments above. Between 44 and 0cm elemental abundances increase sharply, attaining maximum values of 4.23% for carbon and 0.63% for nitrogen. Most C/N ratios are in the range of 4 to 10 and exhibit no trends with depth (Fig. 36).

The transitional changes evident in coloration, $\delta^{13}C$ and elemental abundances seen in this core at 44cm are also evident in core SB3 between unit 1 to subunit 2a. Therefore, the changes in geochemical and sedimentary characteristics at 44cm are interpreted as representing the transition from unit 1 above, to unit 2a below. These are

the only units which were recovered by this core.

4e. Core HB2

A total of 298cm was recovered in core HB2. This core was collected from Halls Bay, a fjord 20km southeast of Green Bay, that also opens up into Notre Dame Bay (Fig. 4). The upper 165cm of sediment consists of a fine silty, olive gray (5Y 4/2) mud with heavy black mottling. Below 165cm the sediment is only lightly mottled, dark gray (5Y 4/1) and has a high carbonate content.

Nitrogen isotope values range from 6.0 to 7.8°/oo with no consistent pattern of variation throughout the core (Fig. 37). The $\delta^{13}C$ range from -22.9 to -21.2°/oo throughout the core (Fig. 37). From 170 to 150cm a slight increase in $\delta^{13}C$ is obsetved. Similarly, carbon and nitrogen abundances increase across this transition and generally continue to increase to 0cm (Fig. 38). Carbon and nitrogen concentrations above 165cm range from 1.44 to 2.88% and 0.23 to 0.44%, for carbon and nitrogen, respectively. Elemental C/N values are highly variable throughout this core, and range from 6.2 to 21.6 (Fig. 39). A large number of high C/N values occur in the lower part of the core (Fig. 39). Two units are recognized in core HB2 based on its similarity in geochemical and sedimentological changes to cores SB3 and GB2. Unit 1 is identified between

0 and 165cm and subunit 2a from 165cm to the core bottom.

4f. Core EX6: trigger weight and piston core

Coring at station EX6 took place where Exploits Bay opens into Notre Dame Bay (Fig. 4). Sediment recovery was 114cm for the trigger weight core and 403cm for the piston core. Three sedimentary units are distinguishable in the piston core and 2 within the trigger weight core.

The bottom 5cm of the piston core consists of a reddish brown (2.5YR 4/4) mud with a fine silty texture. The one sample taken from this interval is characterized by low $\delta^{15}N$ and $\delta^{13}C$ values of 4.9 and -24.7°/oo, respectively (Fig. 40). Abundances of organic carbon, 0.31%, and nitrogen, 0.05%, are also low in comparison to the rest of the core (Fig. 41).

Between 398 and 353cm the sediment is a dark grayish brown (2.5Y 4/2) heavily mottled black with numerous bivalve shells and a 1cm, round carbonate dropstone at 383cm. The carbon and nitrogen isotope values, approximately -22°/oo and 7°/oo, respectively, are more enriched than those of the sediments below. Changes in the sedimentary and geochemical characteristics between sediments below 398cm and those in the interval of 398 to 353cm are similar to changes observed between zones 2c-2 and 2c-1 of core SB3. Consequently, the two sedimentary

intervals below 353cm are classified as zones 2c-2 and 2c-1. No diatomaceous laminations are present in core EX6. This suggests that they were not deposited at this location or that the core did not penetrate far enough into the sediment to sample them.

From the top of subunit 2c to a depth of 348cm the sediment has a grayish brown (2.5Y 4/2) color and a very high carbonate content. Although similar to zone 2c-1 in $\delta^{15}N$, this interval is depleted in $\delta^{13}C$, %C, %N and C/N (Figures 40, 41 and 42). Nearly identical isotopic and elemental values are observed between this interval and subunit 2b of core SB3 indicating that they are composed of the same subunit.

Above subunit 2b to a depth of 139cm the sediment is dark gray (2.5Y 4/) with a moderate carbonate content. Isotope values are variable and range between 6.2 to 8.3°/oo and -22.8 to -21.3°/oo for carbon and nitrogen, respectively. Elemental abundances are constant throughout most of the unit at levels of 0.5% for carbon and 0.1% for nitrogen and are similar to subunit 2c.

From 139cm to the core top the sediment consist of an olive gray (5Y 4/2) silty mud with black mottling. Increases in $\delta^{15}N$ and $\delta^{13}C$ of 1°/oo are noticeable from the top few samples in subunit 2a to the bottom few samples in the unit above. Over this same interval the organic

abundances increase as well, reaching concentrations near 3.0 and 0.5% for carbon and nitrogen, respectively. As in other cores, these changes indicate that this uppermost interval is unit 1.

Within the trigger weight core the color change between sediments below 77cm to those above is similar to the color change observed at 139cm in the piston core. A slight increase in $\delta^{13}C$ and large increases in elemental compositions are observed between sediments below and those above 77cm (Figures 43 and 44). Only a small variation in $\delta^{15}N$ occurs throughout the core (Fig. 43). Ratios of carbon to nitrogen in the trigger weight are similar to those in the upper portion of the piston core (Fig. 45). These results indicate that the transition from unit 1 to unit 2a is located at 77cm in the trigger weight core. Recovery of unit one was much less in this core than in the piston suggesting that the upper portion of this unit was lost either by flowing out the top of the core or upon impact at the sediment water interface.

4g. Core ND2

Collection of core ND2 took place 23km north of core EX6 and formed a transect with EX6 and core SB3 (Fig. 4). Sediment recovery extended to 348cm for this core. From 340cm depth to the core bottom the sediment is reddish gray

(10R 5/1) with $\delta^{15}N$ and $\delta^{13}C$ values near 6.3 and -22°/oo, respectively (Fig. 46). Sediments below 340cm in core ND2 are similar in isotopic composition and coloration to those of subunit 2c-2 in SB3 (Fig. 24, 25, and 46). Elemental abundances for carbon, 0.5%, and nitrogen, 0.07%, are nearly constant within this interval and throughout the core (Fig. 47). Values of C/N are less than 10 for this interval and the majority of the core (Fig. 48).

Between 340 and 313cm the sediment is olive gray (5Y 5/2), with a moderate amount of carbonate and has several thin diatomaceous laminations. Nitrogen isotope values are similar to those of the sediments below. A progressive depletion in ^{13}C occurs from the bottom to the top of this interval.

Above 313cm, to a depth of 295cm, a grayish brown color (2.5Y 5/2) dominated and carbonate content is high. The trend of decreasing $\delta^{13}C$ observed in the sediments below continues, reaching a minimum of -24.1°/oo at 310cm. Values of C/N, 24.7, within this interval are extreme relative to the rest of the core (Fig. 48). Changes in isotope values and coloration between 313 to 340cm and those between the depths of 295 to 313cm are similar to changes observed between zone 2c-1 and subunit 2b in cores SB3 and EX6. Consequently, sediments between 313 to 340cm are identified as zone 2c-1 and those between 295 and 313cm

as subunit 2b.

Above subunit 2b a light olive gray (5Y 6/2) dominates the sediment. A diatom lamination is present at a depth of 287cm. Increases of greater than 1°/oo in both $\delta^{15}N$ and $\delta^{13}C$ occur from the bottom of subunit 2b (313 cm) to a depth of 250cm. No further changes in $\delta^{15}N$ are evident from 250cm to the top of this core. The $\delta^{13}C$ remains approximately constant to 20cm.

The coloration of sediments above 17cm is olive gray (5Y 4/2) with heavy mottling. These sediments are enriched in $\delta^{13}C$ by more than 1°/oo relative to those between 295 and 17cm. Coupled with the change in $\delta^{13}C$ are sharp increases in the organic abundances which reach maximum concentrations at the core top of 1.95 and 0.38% for carbon and nitrogen, respectively. These changes in sediment coloration and geochemistry at 17cm define subunit 2a below and unit 1 above.

4h. Core NS1

Core NS1 was collected 17km from the head of Newman Sound, a fjord that opens into Bonavista Bay (Fig. 5). This core had the lowest sediment recovery, 226cm, of any core within this study. Sediment is olive gray (5Y 4/2) to dark olive gray (5Y 3/2) with heavy black mottling throughout the core.

Nitrogen and carbon isotopes for the entire core varied only 1°/oo and have average values of 7.5 and -20.7°/oo, respectively (Fig. 49). This core has a high abundance of carbon, 5.79%, and nitrogen, 1.01% (Fig. 50). Both of these parameters decrease sharply down core. The total variation in C/N is from 5.0 to 10.9 and no trend with depth is apparent (Fig. 51). Stable isotopic and sedimentary evidence suggest that the entire core is composed of unit 1.

61. Core BB1

Core BB1 was collected from the center of Bonavista Bay and had a total sediment recovery of 556cm (Fig. 5). Sediment coloration and isotopic data in core BB1 are very similar to core NS1. An olive gray (5Y 4/2) to dark olive gray (5Y 3/2) sediment with varying amounts of black mottling dominates throughout the core. Carbon and nitrogen isotope values are very consistent down core and averaged -21.6 and 7.4°/oo, respectively (Figure 52). Core BB1 is not as organic rich as core NS1, with maximum values of 3.35 and 0.63% for carbon and nitrogen, respectively. Between 0 and 180cm a gradual decrease in carbon and nitrogen abundance is evident (Figure 53). Carbon to nitrogen ratios range between 5.1 and 11.9 and do not show much variation with depth (Fig. 54). The sediment

coloration and isotopic composition indicate that the entire length of this core consists of unit 1.

4j. Core summary

Five distinct units were identified and described within the continental shelf sediments off northern Newfoundland. These units have unique sedimentary and geochemical characteristics which are correlated among cores. Within these units a complete sequence of depositional events representing the retreat of the Late Wisconsinan ice sheet and the Holocene interglacial period can be observed.

Discussion

The composition of organic matter preserved in sediments depends on its origin and processes of alteration prior to and after deposition. Through geochemical analysis of this material a history of depositional and climatological events can be obtained. The objective of this study was to assess sources and cycling of organic matter within the bays of northern Newfoundland as a basis for evaluating sources of organic matter preserved in Quaternary sediments. Three endmembers, terrestrial, marine phytoplankton and macroalgae, were characterized by isotopic and elemental analysis for comparison with seston and sedimentary organic matter. Data on seston and sediment from different depths was used to assess diagenesis.

1. Freshwater seston

Freshwater seston has $\delta^{13}C$ values which fell within the range of values reported by previous studies for the terrestrial endmember (-26.5 to -24.8°/oo; Table 1; Peters et al., 1978, Macko 1983). Most seston $\delta^{15}N$ are more enriched than values used to model this endmember (Tables 1 and 4). The ratio of carbon to nitrogen within the terrestrial environment, 14 to 30, is higher than all

values obtained within this study (Table 4; Godell, 1972). Within a freshwater system Minigawa and Wada (1984) interpreted enriched values of $\delta^{15}N$ relative to the terrestrial endmember to be a consequence of phytoplankton. The enriched $\delta^{15}N$ and low C/N values within lacustrine and riverine systems of Newfoundland are suggestive of a freshwater phytoplankton influence.

The Exploits River is unique among freshwaters of Newfoundland. The average $\delta^{13}C$, -25.5°/oo, and $\delta^{15}N$, 2.2°/oo, is 0.6 and 2.8°/oo more depleted than the averages of all other stations. The average C/N, 12.3, is greater than the average of 8.1 obtained for the other freshwaters. Unlike other rivers, the Exploits River is influenced by paper mill effluent. This effect could lead to the depletions observed in the stable isotope values.

The freshwater terrestrial seston data suggests that within the northern Newfoundland system the terrestrial endmember is influenced by both freshwater phytoplankton and an allocthonous input from runoff and paper mill effluent. Consequently, the signature of this endmember would be between the average $\delta^{13}C$ and $\delta^{15}N$ for freshwater seston influenced by phytoplankton, -24.9 and 5.1°/oo respectively, and the average $\delta^{13}C$ and $\delta^{15}N$ of Exploits River seston, -25.5 and 2.2°/oo respectively.

2. Macroalgae

Macroalgae from northern Newfoundland has nitrogen isotope values which fall within a range, 3.9 to 7.7/oo, which was approximately 2°/oo depleted relative to that reported by Miyake and Wada (1967). The variation in $\delta^{13}C$ between species is as much as 7°/oo (Table 3). The species, Laminaria solidungula, has an average carbon and nitrogen isotopic composition of -20.3 and 4.6°/oo, respectively. L. solidungula is recognized as a dominant species within this system (Bob Hooper, Dept. of Biology, Memorial University of Newfoundland, personal communication). Consequently, its isotopic composition may be the most characteristic of the macroalgae endmember.

Carbon isotope values of macroalgae can vary with seasons and within a single plant (Stephenson et al., 1984; Fry et al., 1987). The variation over one year can be as much as 7°/oo and within plant differences are as great as 8°/oo. A 4°/oo variation is observed within a single L. solidungula plant from Bonne Bay, Newfoundland (Fig. 12). The homogenized L. solidungula from this study are at least 2°/oo enriched in ^{13}C relative to species of the same genus taken from other high latitude locations (Stephenson et al., 1987; Dunton and Schell, 1987).

This study showed that nitrogen isotope and C/N values also vary within a single plant. The C/N values at the

blade edge and holdfast are at least 6 less than those of the midrib (Fig. 12). Ratios of carbon to nitrogen of less than 10 indicate nitrogen storage (Hanisak, 1983). The low C/N observed along the blade edge and holdfast of the plant denote nitrogen storage. The enriched $\delta^{15}N$ and the low C/N in these areas in comparison to the midrib suggest that there is isotopic discrimination during storage (Fig. 12). Varying degrees of biosynthesis which draw on these storage products may be an important factor in determining the $\delta^{15}N$ of algae.

Among species of macroalgae there is a range of 20 in C/N (Table 3). Four of the eight values were greater than 18. A C/N greater than 10 is an indicator of nitrogen limitation (Hanisak, 1983). High values in this study may reflect a lack of available inorganic nitrogen in the environment of these algae. However, no additional data was collected to assist in discerning the reasons for the low abundance of nitrogen in these macroalgae.

Based on the analysis of macroalgae in this study, it is not possible to define a clear endmember isotopic composition for the northern Newfoundland system. The ^{15}N values of macroalgae overlapped that of seston. However, the algae are more enriched in ^{13}C than all but one of the seston samples (Tables 3 and 7). In that L. solidungula is a dominant species in this area, its isotopic composition

may most closely reflect that of the macroalgae endmember. L. solidungula is more enriched in ^{13}C and more depleted in ^{15}N than 29 of the 33 surface seston samples. Consequently, values of sediment which are depleted in ^{15}N and enriched in ^{13}C relative to seston may reflect the influence of macroalgae.

3. Marine particulate organic matter

The isotopic abundances of carbon and nitrogen in surface water seston off northern Newfoundland are similar to those reported by other studies. Seston had an average $\delta^{13}C$ of -24.3°/oo which is similar to values reported for phytoplankton from high latitude areas (Sackett et al., 1965; McConnaughey and McRoy 1979; Tan and Strain 1983, Dickson 1986, Dunton and Schell 1987, Table 5). The majority of surface seston $\delta^{15}N$ values are within the range of 5 to 9°/oo which is common for phytoplankton from pelagic seas and coastal areas (Minigawa and Wada, 1984, Table 13). Such values are similar to that of oceanic nitrate, the primary source of nitrogen for phytoplankton (Miyake and Wada, 1967; Cline and Kaplan, 1975 and Liu, 1979). It has also been suggested that ammonia assimilation can result in values for seston which range between 6 and 10°/oo (Saino and Hattori, 1980). The C/N of surface water seston is similar to the range reported for

marine phytoplankton (Muller, 1977, Table 7).

The $\delta^{15}N$ and C/N of filamentous material obtained from plankton tows is within the range of the surface seston. The $\delta^{13}C$ of the tow material is enriched relative to the surface seston. This distinction is a consequence of differences in the type or source of material collected by the two sampling devices. Niskin bottles primarily collect suspended POM, which has been termed seston, whereas the larger fraction, sinking POM, is obtained in the plankton tows (McCave, 1975; Altabet, 1988). Suspended material has been shown to be enriched in ^{13}C relative to sinking POM (Entzeroth, 1982). Alternatively, a larger contribution of macroalgae to the plankton tow material could account for the observed enrichment in ^{13}C relative to seston.

Enrichments in the $\delta^{13}C$ of phytoplankton material have also been attributed to isotopic discrimination between HCO_3^- and CO_2 in seawater (Deuser, 1970). During periods of high productivity there is increased utilization of CO_2 which shifts the equilibrium between HCO_3^- and dissolved CO_2 in favor of the production of CO_2. Under these conditions the normally observed 7°/oo equilibrium fractionation effect in $\delta^{13}C$, between $HCO3^-$ and dissolved CO_2, is reduced (Degens et al., 1968b). This leads to enrichments in ^{13}C of dissolved CO_2 and of the phytoplankton which utilize this gas.

The origin of the plankton tow material is uncertain. Isotopic and elemental data suggest that it is mostly composed of phytoplankton with a minor contribution from macroalgae. It is difficult to discern the relationship of this material to the rest of the system because only two samples were obtained. Consequently, the seston samples are considered to be the most representative of marine POM.

Variation observed in the isotopic and elemental abundances of surface water seston reflects changes in the relative input of organic matter from terrestrial, phytoplankton and macroalgae detritus. In May, seston from Exploits and Trinity Bays is characterized by lower $\delta^{15}N$ and higher C/N and organic concentrations than at other times of the year (Table 13). These changes indicate an increased terrestrial influence in May as a consequence of spring runoff. The low $\delta^{15}N$ and high C/N values in Bonavista Bay in May are also interpreted as being influenced by terrestrial runoff.

Depletions in ^{13}C, which normally accompany terrestrial input, are not always observed. At EX4, EX2, and TB5 the carbon values in May, -23.5 to -23.2°/oo, are greater than at other times of the year. This seems to contradict a terrestrial influence since the average value for freshwater seston from the Exploits River is -25.5°/oo. The most enriched $\delta^{13}C$ within Exploits Bay, -22.5°/oo, is

obtained at EX1, the station nearest to the mouth of the Exploits River. The carbon and nitrogen isotope values at EX1 are similar to L. solidungula which suggests a strong macroalgae contribution at this station. A macroalgae influence in May throughout the Exploits and at HB3 in May and ND2 in November could result in the observed enrichments in $\delta^{13}C$.

Excluding stations within Exploits, Trinity and Halls Bays in May and ND2 in November where a terrestrial or macroalgae contribution is observed, low $\delta^{13}C$ values suggested a predominance of phytoplankton detritus. If the above stations are not included, the average for $\delta^{15}N$ and $\delta^{13}C$ is 8.2 ± 1.5 and -24.6 ± 1.6, respectively. These values define the phytoplankton endmember for the bays of northern Newfoundland.

The isotopic and elemental composition of seston from lower waters is a function of sources, degradation and resuspension. Degradation of organic matter typically results in increases in $\delta^{15}N$ and C/N and decreases in $\delta^{13}C$ and organic concentrations (Gordon, 1971; Muller, 1977 and Saino and Hattori, 1980). Diagenetic effects within the water column are evident at many stations by increases in $\delta^{15}N$ in middle and/or bottom water seston relative to surface waters (Figures 14 and 15).

The $\delta^{13}C$ and C/N of seston showed no consistent trends

with depth as opposed to $\delta^{15}N$. The smaller variation in $\delta^{13}C$ relative to $\delta^{15}N$ may be explained by fractionation of ^{15}N during utilization and mobilization of the nitrogen. Microbial activity may increase the nitrogen content of detritus over time (Tenore, 1983). The variable C/N values and organic concentrations of lower water seston in this study may, therefore, be related to the size of the bacterial community present.

At some stations the $\delta^{15}N$ of middle water seston is lower than that of seston above and below (Fig. 14). Similar depletions in ^{15}N have been observed at the base of the euphotic zone and were attributed to isotopic discrimination during assimilation of inorganic nutrients under high concentrations where conditions are non rate limiting (Saino and Hattori, 1980; 1985 and 1987). However, decreases in seston nitrogen isotope values have also been attributed to growth of bacteria utilizing isotopically depleted ammonium (Wada 1980, Libes and Deuser, 1988). Owing to the lack of data on nutrient concentration and isotopic abundances it is not possible in this study to distinguish between these two processes.

Degradation of organic matter in the water column is also indicated by changes in the $\delta^{13}C$ and concentration of DIC with depth (Figures 17 and 19). Average $\delta^{13}C$ values are lowest in bottom waters and greatest in surface waters.

Also evident is an increase in DIC concentration in deeper water samples (Table 10). These two trends indicate an input of isotopically depleted carbon dioxide from the oxidation of organic matter (Kroopnick 1980).

Seston from bottom waters frequently has greater concentrations of total suspended matter and organic carbon and nitrogen than surface and/or middle waters (Table 7). A contribution of sedimentary material to these samples is likely since the majority of bottom samples were collected 5m above the seabed. Near bottom seston $\delta^{13}C$ values have been observed to reflect a mixture of sediments and surface water seston as a consequence of resuspension (Tan and Strain 1979a). Similar shifts in bottom water seston $\delta^{15}N$ and $\delta^{13}C$ values are observed at several stations in this study and indicate resuspension of sediments (Figures 14 and 16). The effects of resuspension may have been observed at all stations had seston been collected nearer to the seabed.

These results suggest that the isotopic and elemental composition of seston in lower waters is affected by productivity, degradation and resuspension. There is a tendency for one process to affect one parameter to a greater extent than it affected others. For example, degradation in middle waters at station HB1 in November resulted in a 5.6°/oo increase in $\delta^{15}N$ with respect to the

surface, but had negligible effects on $\delta^{13}C$ or C/N (Table 6). Resuspension is clearly indicated at GB3 in August by an increase of 2.09mg/l in total suspended matter of bottom water seston with respect to the middle water sample. Both carbon and nitrogen isotope values at GB3 are shifted by greater than 1°/oo, but the change in C/N was minor. These data indicate that degradation and resuspension, either directly from the bottom or from slumping, can affect seston carbon and nitrogen to varying degrees or independently. A clearer interpretation of the processes affecting the isotopic and elemental composition of seston could be obtained by collection and analysis of more samples from different depths at each station.

4. Surficial sediments

Sediments receive organic matter from the water column. The isotopic and elemental composition of sediments within Northern Newfoundland Bays should reflect a mixture of the three endmembers which contribute to the waters of this system. The upper centimeter of sediment material is similar to the phytoplankton endmember in $\delta^{15}N$ and C/N but resembles macroalgae in $\delta^{13}C$ (Table 14). These results infer a mixing of two sources as opposed to diagenesis. The enrichment in ^{13}C of surficial sediments relative to seston contradicts the isotopic trend that is

associated with diagenesis (Eadie and Jeffrey, 1973; Jeffrey et.al., 1983).

A terrestrial influence is observed in Exploits Bay. The $\delta^{13}C$ and C/N of surficial sediments at EX1 are very similar to the terrestrial endmember (Tables 10 and 14). A grab transect in Exploits Bay clearly demonstrates a mixing of terrestrial and marine sources by increases in $\delta^{13}C$ and $\delta^{15}N$ with distance from the head of the estuary (Figures 21 and 22). A similar transect in Conception Bay does not show a similar mixing trend. Isotopic values throughout the Bay are relatively constant and indicative of a mixture of phytoplankton and macroalgae material.

The surficial sediment data demonstrate that isotopic and elemental data can be used in the modern environment to assess the relative contribution of sources of organic material to the sediments. Information regarding variations in this input over time is retained in core samples. However, diagenesis in sediments must be assessed to determine if this process obscures the geochemical signature of the source material.

Decomposition may be responsible for the wider range of $\delta^{15}N$ and greater C/N values when samples were stored for one and one-half years in the laboratory at room temperature (Table 12). However, it is difficult to make a firm conclusion of the basis of these few samples. More

samples are needed from this and other cores to assess the organic geochemical changes that occur to sediments under storage. Diagenesis is not apparent in the upper 3cm of the sediments. The average isotopic and elemental composition of samples taken at 0 and 3cm are nearly identical (Table 9). The geochemical signature is preserved and therefore the ability to assess the relative contributions of organic sources was maintained in upper sediments.

5. Sediment cores

5a. Diagenesis

Evaluation of core data similarly depends on the ability to distinguish changes due to source from those which are a consequence of diagenesis. The latter effect is indicated by decreases in the organic abundance of carbon and nitrogen down core (Montani et. al, 1980; Waples and Sloan, 1980). Such trends are apparent in all cores from this study (Figures 26, 29, 32, 35, 38, 41, 44, 47, 50 and 53). Enrichments in ^{15}N and depletions in ^{13}C over the same interval where organic abundances decrease have been attributed to diagenesis (Behrens and Frishman, 1971; Macko, 1981). Concomitant decreases in $\delta^{13}C$ and carbon and nitrogen abundances are observed in core WB7 (Figures 31 and 32). No definitive trends are observed in $\delta^{15}N$ with

depth. Decreases in $\delta^{13}C$ and organic abundances between unit 1 and 2a of cores SB3 and ND2 are accompanied by changes in sediment coloration. As will be discussed later this color change implies a change in sediment characteristics which is probably related to a change in source. Core WB7 is the only core where diagenesis is clearly indicated by isotopic trends.

With the exception of core WB7, diagenesis is not considered a dominant factor in controlling the isotopic composition of sediment cores. Therefore, the data from this study is used to assess changes in the relative contribution of endmembers as a function of climatological events from the late Wisconsinan through the Holocene.

5b. Interpretation of depositional events

The most complete sequence of depositional events is represented by core SB3. For the sedimentary record represented by this core, isotopic and elemental data evidence the retreat of the late Wisconsinan ice sheet. Ice movements are reflected by changes in the relative contributions of organic matter sources and sedimentological characteristics. A regional interpretation is provided by correlations among cores.

The earliest depositional event represented by unit 5 of core SB3 is interpreted as till that was deposited

during the Late Wisconsinan glacial maximum. This material is considered to have originated from Carboniferous bedrock located west of core SB3 (Mudie and Guilbault, 1982). The average $\delta^{13}C$, -25.3°/oo and average $\delta^{15}N$, 4.3°/oo, for unit 5 are similar to the isotopic composition of freshwater seston considered to be of phytoplankton origin (Table 5 and Fig. 23). Similar isotope values are reported by Pulchan (1987) for a glacial till deposited in marine sediments from Bay D'Espoir, Newfoundland. The C/N values are lower than that of the Exploits river seston but most fall within the range of fresh water seston (Tables 4 and 14, Fig. 27). The geochemical evidence indicates that the sediment in unit 5 was initially deposited during the Carboniferous in a freshwater environment prior to glacial transport.

Previous work suggested that Unit 4 was deposited shortly after separation of the grounded ice sheet from the sea floor (Mudie and Guilbault, 1982). The $\delta^{15}N$ and C/N values are similar to unit 5. An increase of 1.7°/oo in the average $\delta^{13}C$ of unit 4 relative to unit 5 may indicate a small contribution of marine organic matter (Fig. 23). After separation waters below the ice sheet could have exchanged with those further offshore resulting in mixing of till and marine organic matter.

A greater marine influence is evidenced in unit 3 by

diatom laminations and $\delta^{15}N$ values near 6°/oo at the base of this unit (Fig. 26). The retreat of the ice sheet over this location is implied by these data and the observed decrease in the abundance of sand from the bottom of the core through unit 3 (Fig. 24). Ages of 21,000 and 17,000 yr BP has been proposed for this event (Mudie and Guilbault, 1982; Scott et al., 1984). Carbon and nitrogen isotope values of the upper sediments of unit 3 are similar to unit 4. Within unit 3 these $\delta^{15}N$ values can be accounted for by release of till as the ice sheet melted or preferential degradation of marine organic matter and preservation of the signal from the more refractory terrestrial till.

The sediments of unit 2c are similar in isotopic and C/N composition to that which would result from a mixture of macroalgae and phytoplankton (Figures 25 and 27). The weakening influence of till and predominance of phytoplankton is indicated by increases in $\delta^{15}N$ up core within zone 4. Enrichments in ^{13}C from the bottom of zone 4 through zone 3 may reflect a contribution of macroalgae. The productivity of macroalgae growing at depth would be enhanced by increased light attenuation associated with extensive ice free conditions. Surface phytoplankton could flourish with partial ice cover. Reductions in ice cover could account for the influence of macroalgae organic

matter observed in zone 3.

Although a marine influence continues to dominate the geochemical parameters of sediments within zone 2, a reddish gray coloration suggests deposition of till. The low sand content within this zone suggests that the till was not deposited in close proximity to core SB3 (Fig. 24). Sediments in zone 2 of core ND2 are similar to zone 2 of core SB3 in isotopic composition and sediment coloration (Fig. 46). However, in core EX6 the reddish sediment is accompanied by $\delta^{13}C$ and $\delta^{15}N$ values similar to those of unit 5 of core SB3 (Fig 40). The isotope values of sediments within zone 2 of EX6 indicate a second deposition of till in close proximity to this core. The till may have been flushed into the Notre Dame basin. Organic concentration of the till is low and not sufficient enough to overprint the marine signature prevalent in zone 2 of cores SB3 and ND2 (Figures 26, 41, and 47).

Decreases in $\delta^{13}C$ and C/N up core in zone 1 of subunit 2c and subunit 2b within cores SB3 and EX6 are characteristic of an increased contribution from phytoplankton relative to macroalgae. The $\delta^{15}N$ of 6°/oo is low relative to the phytoplankton endmember but is within the range of surface water seston (Tables 7 and 14). Shifts in the nitrogen isotopic composition of phytoplankton may be related to variation in the abundance

and isotopic composition of inorganic nitrogen (Cline and Kaplan, 1975; Saino and Hattori, 1987).

Subunit 2b of core ND2 has a similar isotope composition to subunit 2b of cores SB3 and EX6. The C/N values in subunit 2b of ND2 of greater than 20 are strongly indicative of terrigenous organic matter. This subunit is characterized by a very high carbonate content considered to be detrital in origin (Dale, 1979). The high carbonate content of subunit 2b distinguishes it from the carbonate poor till. Transport of detrital carbonate and localized deposition of terrigenous material could have resulted from ice rafting.

A phytoplankton signature dominates the sediments of subunit 2a of core SB3. At core sites EX6, ND2, GB2 and HB2 subunit 2a has $\delta^{15}N$ values which are similar to those of subunit 2a of core SB3 but $\delta^{13}C$ are greater and range between -21.3 and -23.2°/oo (Figures 25, 34, 37, 40 and 56). The enrichments in ^{13}C reflect a greater contribution of macroalgae at these inshore stations. Within subunit 2a of core HB2 C/N values greater than 10 could result from a contribution of terrestrial organic matter (Fig. 39).

An age of 10,000 yrs BP has been estimated for the base of unit 1, which has been suggested to represent sedimentation after complete deglaciation of Newfoundland (MacPherson, 1988). Aside from evidence of a terrestrial

input observed in the $\delta^{13}C$ and C/N of the upper 10cm of core WB1, unit 1 is dominated by marine organic matter (Figures 28 and 30). The majority of $\delta^{15}N$ values and C/N values for unit 1 of all cores are typical of a mixture of phytoplankton and macroalgae organic matter. A greater contribution of macroalgae relative to phytoplankton in most samples of unit 1 is suggested by $\delta^{13}C$ values which are enriched relative the phytoplankton endmember (Fig. 49). This macroalgae predominance is most evident at NS1.

Conclusions

Isotopic tracers in combination with elemental analyses are useful in distinguishing among three sources of organic matter, terrestrial, macroalgae and phytoplankton, which influenced the waters and sediments off northern Newfoundland. Seston from most locations is primarily composed of phytoplankton. In May, Trinity, Exploits and Bonavista Bays show a terrestrial input in surface seston samples. The majority of surficial sediments reflect a mixture of phytoplankton and macroalgae detritus. A terrestrial influence is reflected only in surficial sediments of Exploits Bay.

The geochemistry of seston and DIC from the lower water column is related to sources, degradation and

sediment resuspension. It is possible that these processes act independently to affect the isotopic and elemental composition of lower seston. Diagenesis is observed to alter isotopic abundances in water column suspended POM. However, in only one core are sediments affected by this process. Consequently, in other cores the isotopic signatures are considered to indicate organic matter sources.

Through geochemical characterization of sediment cores the retreat of the Wisconsinan ice sheet is documented and correlated among cores. Isotopic and elemental parameters show a decrease in the influence of terrestrial organic matter within glacial till and an increased marine influence up core. Within marine sediments a variation in the dominance of phytoplankton and macroalgae is observed.

Geochemical data provide a method for assessing the origins of sediments. This is particularly useful in the absence of microfossil assemblages. New developments in isotope science which involve the isolation and analysis of compounds may assist in a more accurate evaluation of diagenesis and origins of organic matter.

Table 1. Carbon and nitrogen isotopic compositions of dominant organic matter sources (endmembers) to marine sediments.

Terrestrial		Marine				Location and Reference
		Phytoplankton		Macroalgae		
$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	
2	-25	6	-21	8	-22	Gulf of Maine: Mayer et al., 1988
4	-25	9	-22	7	-21	Baffin Island, Canadian Arctic: Macko et al., 1987b
1.8	-26.5	6.3	-20.3			Otsuchi River Watershed, Japan: Wada et al., 1987a
3.1	-25.2			6.8	-21.0	Canadian Arctic Archipelago: Pereira and Macko, 1986
0	-24.8	6.2	-21.2			U.S. east coast: Macko et al., 1984
		7.5	-21.0			Northwest Gulf of Mexico: Macko et al., 1984
		-0.9	-19.4			Southeast Gulf of Mexico: Macko et al., 1984
2	-26	10	-21			Northeast Pacific Ocean: Peters et al., 1978
2.5	-24*	10	-22			Southern California Coast: Sweeney et al., 1980 and Sweeney and Kaplan, 1980a

* These values are a characterization of terrestrial sewage.

Table 2. Time and subsurface depth of aliquots used in settling column determination of silt and clay abundances (adapted from Folk, 1980).

Time	Subsurface depth (cm)
20 sec.	20
2 min.	20
4 min.	20
8 min.	20
15 min.	20
30 min.	10
2 hr.	10
8 hr.	10

Table 3. Isotopic and elemental analysis of potential contributers of organic matter to the water column and sediments of northern Newfoundland.

Sample*	$\delta^{15}N$(°/oo)	$\delta^{13}C$(°/oo)	C/N
Fucus vesiculosis leaf	5.6	-13.0	27.79
Ascophyllum nodosum leaf	4.5	-13.9	**
Saccorhiza dermatodea 1	6.5	-16.2	26.70
Saccorhiza dermatodea 2	6.9	-17.6	24.54
Laminaria digitada leaf	7.3	-13.8	18.67
Laminaria digitada stem	7.7	-17.4	7.78
Laminaria solidungula 1	5.0	-21.0	10.05
Laminaria solidungula 2	4.9	-20.4	8.74
Laminaria solidungula 3	3.9	-19.6	8.72
Zostera marina leaf	4.8	-9.3	17.36
Zostera detritus	4.6	-9.9	24.04
Plankton tow Exploits Bay	9.9	-21.5	3.87
Plankton tow White Bay	9.2	-21.5	5.16
Brook sediment (Big Brook NF)	3.9	-27.7	12.22

* Unless other wise specified the entire plant was analyzed. The *Fucus* and *Ascophyllum* plants were collected offshore in Bay of Isles in 5/87, as were the plankton tows. *Laminaria solidungula* plants were collected using SCUBA from Bonne Bay in 8/87. Other algae were collected using SCUBA from Logy Bay in 6/87.

** Not determined.

Table 4. Seston data for terrestrial stations collected on 5/29/87.

ID	Location	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	µgC/l	µgN/l	C/N	TSM (mg/l)
SL1	Sandy Lake	3.3	-25.2	197	25	9.3	0.61
BB2	Burnt Berry Brook	5.6	-24.8	160	21	8.6	*
SO3	South Brook	4.4	-24.4	87	13	7.8	0.39
BA4	Badger Brook	5.3	-25.2	120	16	8.9	0.35
BA4	Badger Brook	6.1	-24.2	92	21	5.1	0.50
ER5	Exploits River	2.3	-25.2	261	30	10.2	0.53
ER5	Exploits River	1.6	-26.0	451	39	13.4	0.87
ER5	Exploits River	2.8	-25.4	469	41	13.5	1.00
IA6	Indian Arm Brook	4.0	-25.5	101	13	9.1	0.31
BI7	Big Brook	5.3	-25.7	121	17	8.4	0.59
SH8	Shoal Harbour River	6.5	-24.4	85	13	7.9	0.14

TSM - total suspended matter.
* Data was lost in handling.

Table 5. Mean and standard deviation data on $\delta^{15}N$, $\delta^{13}C$ and C/N of seston samples from surface, middle and bottom waters.

Sample* depth	$\delta^{15}N$(°/oo) mean ± σ	$\delta^{13}C$(°/oo) mean ± σ	C/N mean ± σ
Surface	7.4 ± 2.0	-24.3 ± 1.5	7.8 ± 3.1
Middle	7.9 ± 2.9	-24.6 ± 1.6	6.7 ± 3.4
Bottom	9.0 ± 2.4	-24.1 ± 1.3	8.7 ± 5.8

* Surface waters were taken from 2 - 6m, middle waters from 90 - 115m, bottom waters were taken approximately 5m above bottom and ranged in depths of 160 - 633m.

Table 6. Isotopic, elemental and total suspended matter data of seston samples for all research surveys.

Stn.	Depth (m)	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	µgC/l	µgN/l	C/N	TSM* (mg/l)	Date (m/d/yr)
WB1	3	10.1	-24.3	42	5	9.1	**	11/17/86
WB1	115	10.1	-24.9	34	4	9.2	**	
WB1	231	10.1	-23.9	63	7	11.2	**	
WB1	4	11.7	-29.7	29	12	2.8	2.13	5/27/87
WB1	100	8.1	-22.3	41	10	5.0	0.50	
WB1	236	8.8	-23.0	76	11	8.1	0.81	
WB1	5	8.8	-25.6	33	10	3.8	1.02	8/15/87
WB1	100	3.6	-24.3	18	6	3.4	0.10	
WB1	265	10.2	-24.0	46	10	5.7	1.36	
WB7	3	8.5	-24.3	46	6	8.7	**	11/17/86
WB7	200	***	-24.0	41	***	***	**	
WB7	390	10.0	-23.3	58	11	6.3	**	
WB6	5	9.2	-21.7	95	13	8.3	0.33	5/27/87
WB6	100	***	-21.0	60	12	5.9	0.43	
WB6	418	6.5	-21.5	112	13	10.3	1.57	
WB6	5	7.3	-24.4	42	9	5.8	0.24	8/15/87
WB6	100	10.5	-24.6	28	8	4.3	0.09	
WB6	420	11.2	-23.0	41	9	5.4	0.69	
SB4	3	7.9	-23.3	42	6	8.7	**	11/17/86
SB4	149	11.2	-23.4	84	11	8.8	**	
SB4	302	9.8	-24.1	97	8	14.5	**	
SB2	6	8.5	-25.1	53	10	6.0	0.18	5/26/87
SB2	96	7.4	-24.2	48	11	5.1	0.50	
SB2	277	9.1	-24.9	60	10	7.2	0.87	
SB2	5	9.0	-26.3	38	10	4.3	1.56	8/15/87
SB2	100	2.6	-24.6	18	6	3.4	0.74	
SB2	286	8.5	-25.3	25	8	3.7	1.36	
GB1	3	9.0	-24.2	38	6	7.4	**	11/18/86
GB1	100	10.3	-23.9	38	5	8.4	**	
GB1	181	11.3	-24.4	46	7	8.1	**	

* TSM = Total suspended matter. *** Data lost in handling
** Data was not collected

Table 6. Continued

Stn.	Depth (m)	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	µgC/l	µgN/l	C/N	TSM (mg/l)	Date (m/d/yr)
GB3	5	8.7	-24.5	76	11	8.3	0.24	8/14/87
GB3	100	11.1	-26.9	33	8	5.2	0.53	
GB3	245	8.0	-25.4	55	12	5.5	2.64	
HB1	2	8.2	-23.8	29	5	6.5	**	11/18/86
HB1	90	11.8	-24.4	31	4	7.6	**	
HB1	169	13.8	-23.7	25	5	6.1	**	
HB3	4	6.8	-22.5	98	12	9.2	0.35	5/26/87
HB3	99	5.8	-25.2	43	10	5.3	0.35	
HB3	310	8.1	-25.7	29	9	3.7	0.74	
ND2	2	5.0	-23.3	42	5	9.3	**	11/18/86
ND2	181	6.7	-24.9	35	4	9.3	**	
ND2a	361	7.8	-23.0	62	7	10.7	**	
ND2b	361	7.0	-22.7	84	9	11.0	**	
ND2	5	6.1	-24.1	70	10	8.1	0.64	5/26/87
ND2	100	7.3	-23.2	74	11	7.8	0.57	
ND2	214	13.1	-24.8	45	12	4.5	0.67	
ND2	5	7.4	-27.7	33	9	4.3	0.22	8/14/87
ND2	100	1.5	-25.3	16	7	2.6	0.83	
ND2	366	9.2	-27.8	23	9	3.0	1.28	
EX6	4	3.8	-23.6	37	10	4.2	**	11/19/86
EX6	301	4.5	-24.1	33	5	7.4	**	
EX6	589	5.4	***	33	8	5.0	**	
EX6	5	5.7	-23.3	111	14	9.2	0.47	5/25/87
EX6	100	9.3	-23.9	113	15	9.0	0.74	
EX6	620	9.3	-24.0	90	10	10.7	0.45	
EX6	5	7.2	-23.5	62	13	5.7	1.09	8/14/87
EX6	100	10.6	-24.0	58	10	6.6	0.33	
EX6	633	11.9	-24.9	30	9	3.8	0.90	
EX4	5	6.3	-23.5	130	14	10.8	0.71	5/25/87
EX4	102	2.4	-23.0	114	11	11.7	0.60	
EX4	488	9.4	-24.0	91	10	11.1	0.78	

ND2 a and b are replicate samples.

Table 6. Continued.

Stn.	Depth (m)	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	µgC/l	µgN/l	C/N	TSM (mg/l)	Date (m/d/yr)
EX4	5	8.6	-24.5	68	13	6.0	0.84	8/14/87
EX4	100	10.8	-24.6	30	9	3.7	0.58	
EX4	497	9.6	-23.0	66	10	8.0	0.57	
EX3	5	2.7	-23.2	80	11	8.7	0.74	5/25/87
EX3	100	10.8	-24.2	80	12	8.0	0.87	
EX3	243	1.5	-23.1	117	11	12.9	0.95	
EX3	5	6.9	-23.0	80	13	7.5	0.09	8/13/87
EX3	100	8.5	-25.2	34	9	4.4	0.40	
EX3	231	11.8	-22.3	55	10	6.2	0.55	
EX2	5	3.6	-23.7	104	10	12.6	1.62	5/25/87
EX2	55	16.8	-24.2	68	12	6.9	0.71	
EX2	110	8.5	-24.5	133	12	13.1	0.75	
EX2	5	7.0	-24.8	95	15	7.4	1.10	8/13/87
EX2	100	9.3	-23.7	59	10	7.2	0.55	
EX2	110	10.1	-25.1	46	10	5.3	1.95	
EX1	6	4.2	-22.5	148	16	10.6	0.73	5/25/87
EX1	22	4.6	-22.7	146	15	11.7	0.78	
EX1	45	4.7	-23.0	162	16	11.6	1.20	
BB1	5	6.8	-24.2	100	11	10.2	0.40	5/24/87
BB1	100	5.0	-23.6	139	12	13.5	1.26	
BB1	294	7.4	-23.4	239	14	19.5	1.21	
NS1	4	9.3	-23.7	104	12	9.7	**	11/21/86
NS1	100	10.4	-23.6	33	5	7.9	**	
NS1	255	9.5	-24.4	15	6	3.0	**	
TB6	5	6.1	-25.6	174	14	15.0	0.80	5/23/87
TB6	100	5.1	-24.9	120	8	16.8	0.75	
TB6	322	6.5	-25.0	314	13	27.4	2.15	
TB6	5	8.8	-24.7	37	10	4.4	1.16	8/12/87
TB6	100	9.8	-25.3	52	10	6.0	1.46	
TB6	321	9.4	-27.3	30	11	3.0	1.38	

Table 6. Continued.

Stn.	Depth (m)	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	µgC/l	µgN/l	C/N	TSM (mg/l)	Date (m/d/yr)
TB5	5	6.4	-23.5	176	12	17.0	0.50	5/23/87
TB5	100	5.4	-25.1	101	10	11.5	0.65	
TB5	570	4.6	-23.6	234	11	24.8	1.27	
TB5	5	8.4	-25.7	31	9	3.9	1.93	8/12/87
TB5	100	8.2	-30.0	14	9	1.8	0.78	
TB5	578	9.9	-23.2	58	11	6.3	0.55	
RS1	5	9.7	-23.6	43	9	5.5	0.20	8/12/87
RS1	100	8.4	-25.6	38	10	4.6	0.07	
RS1	160	9.3	-25.2	32	9	4.0	**	
CB3	100	8.8	-27.7	18	9	2.4	1.65	8/18/87
CB3	254	8.6	-24.3	111	12	10.5	5.25	

Table 7. Mean and standard deviation data on concentrations of total suspended matter, organic carbon and nitrogen of seston samples from surface, middle and bottom waters.

Sample depth	μgN/l mean ± σ	μgC/l mean ± σ	TSM(mg/l)* mean ± σ
Surface	10 ± 3	72 ± 41	0.77 ± 0.55
Middle	9 ± 3	53 ± 34	0.64 ± 0.38
Bottom	10 ± 2	77 ± 66	1.27 ± 1.02

* TSM = total suspended matter.

Table 8. Mean and standard deviation data on $\delta^{13}C$ and concentration of DIC.

Sample* depth	$\delta^{13}C$(°/oo) mean ± σ	Conc.(mM/kg) mean ± σ
Surface	-3.1 ± 1.7	1.50 ± 0.38
Middle	-4.4 ± 2.3	1.70 ± 0.25
Bottom	-6.1 ± 1.8	1.68 ± 0.34

* Surface water samples were taken 1-14m, middle samples 22-131m, and bottom samples 189-626m.

Table 9. Mean and standard deviation data on $\delta^{15}N$, $\delta^{13}C$, %N, %C and C/N of grab samples.

Sample depth (cm)	$\delta^{15}N$ mean ± σ (°/oo)	$\delta^{13}C$ mean ± σ (°/oo)	%N mean ± σ	%C mean ± σ	C/N mean ± σ
0	7.6 ± 1.1	-21.8 ± 1.1	0.66 ± 0.34	3.67 ± 2.06	6.7 ± 2.9
3	7.6 ± 0.9	-21.4 ± 0.7	0.66 ± 0.34	3.60 ± 1.80	6.7 ± 2.1

Table 10. Isotopic and elemental data on grab samples.

Station*	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	%C	%N	C/N	Date (m/d/yr)
EX1S**	5.4	-24.8	7.18	0.61	13.8	9/6/86
EX1B	5.6	-23.4	4.32	0.63	8.0	
EX1S	5.1	-25.1	5.69	0.43	15.4	5/25/87
EX1B	6.7	-23.2	5.65	0.79	8.3	
EX2S	5.8	-22.9	6.61	1.00	7.7	5/25/87
EX2B	7.0	-22.0	6.73	0.95	8.3	
EX2S	6.4	-22.7	6.77	1.40	5.7	8/13/87
EX2B	6.1	-21.7	4.91	0.90	6.4	
EX3S	6.7	-22.2	4.41	0.44	11.8	5/25/87
EX3B	7.0	-21.6	4.31	1.05	4.8	
EX4S	8.0	-21.8	7.38	1.22	7.0	8/14/87
EX4B	7.5	-21.4	7.17	1.46	5.7	
EX6S	8.4	-21.0	5.08	0.89	6.7	8/14/87
EX6B	8.5	-20.5	4.49	0.75	6.9	
ND2S	7.1	-20.9	1.02	0.23	5.2	8/14/87
ND2B	6.7	-20.9	1.15	0.23	5.8	
HB1S	7.0	-22.0	2.13	0.59	4.2	5/26/87
HB1B	6.9	-21.7	1.86	0.17	13.1	
HB3S	6.8	-20.9	4.84	0.93	6.1	5/26/87
HB3B	6.9	-20.8	3.69	0.67	6.4	
HB5S	7.7	-21.2	2.74	0.83	3.9	5/26/87
HB5B	7.2	-21.2	2.93	0.77	4.5	
GB1S	8.8	-21.4	3.26	0.57	6.7	8/14/87
GB1B	8.4	-21.4	4.40	0.81	6.4	
GB4S	9.4	-21.1	3.11	0.75	4.8	8/14/87
GB4B	8.2	-21.0	3.44	0.65	6.1	

* Station abreviations are the same as are in appendix 1.
** S = surficial sediment, B = sediment at a depth of 3cm.

Table 10. Continued.

Station*	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	%C	%N	C/N	Date (m/d/yr)
WB1S	7.4	-22.3	3.92	0.93	4.9	8/15/87
WB1B	8.3	-22.0	4.12	0.42	11.5	
WB8S	8.7	-21.0	3.07	0.54	6.7	8/15/87
WB8B	8.0	-20.9	2.09	0.39	6.3	
CB1S	8.0	-21.5	3.28	0.60	6.4	8/18/87
CB1B	9.1	-21.3	3.44	0.69	5.8	
CB2S	7.8	-21.2	3.15	0.96	3.8	8/18/87
CB2B	8.4	-21.0	3.55	0.56	7.4	
CB3S	8.7	-21.2	4.07	0.69	6.9	8/18/87
CB3B	8.1	-21.2	3.08	0.71	5.1	
CB4S	8.3	-21.4	1.64	0.28	6.9	8/17/87
CB4B	7.3	-21.2	1.80	0.49	4.3	
CB5S	9.0	-21.1	0.78	0.19	4.9	8/17/87
CB5B	7.7	-21.1	0.65	0.16	4.8	
RS5S	7.6	-21.5	3.49	0.96	4.3	8/12/87
RS5B	8.0	-21.2	5.62	1.21	5.4	
OF1S	8.6	-21.0	0.43	0.10	4.9	8/15/87
OF1B	9.0	-21.0	0.19	0.04	5.8	
OF2S	7.8	-21.1	0.44	0.08	6.1	8/15/87

Table 11. Newman Sound piston core data: samples removed 3 weeks after collection in comparison to samples maintained at room temperature for 1 1/2 years.

Sample set*	Depth (cm)	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	%C	%N	C/N
NS1	0	7.5	-20.8	5.79	1.01	6.7
NS1	10	7.8	-20.7	4.40	1.03	5.0
NS1	30	7.8	-20.6	4.84	0.72	7.8
NS1	40	7.8	-20.3	3.50	0.63	6.5
NS1	50	7.6	-20.4	4.39	0.62	8.3
NS1	60	7.6	-20.7	3.24	0.62	6.2
NS1	70	7.8	-20.6	4.00	0.62	7.6
NS1	80	7.2	-20.6	2.78	0.47	6.9
NS1	90	7.2	-20.6	2.71	0.32	9.8
NS1	100	7.2	-20.6	2.11	0.27	9.1
NSD	5	7.5	-20.5	5.58	1.43	4.5
NSD	15	6.8	-20.2	5.62	1.19	5.5
NSD	25	7.4	-20.2	6.97	0.75	10.9
NSD	35	7.3	-20.0	4.64	0.66	6.5
NSD	45	7.5	-20.2	3.87	0.38	12.0
NSD	55	7.3	-20.3	3.49	0.41	10.0
NSD	65	7.9	-20.3	3.74	0.37	11.9
NSD	75	7.6	-20.5	2.86	0.33	10.2
NSD	85	7.8	-20.7	2.94	0.28	12.5
NSD	95	8.3	-20.6	2.48	0.28	10.4

* NS1 samples were taken from the core 3 weeks after collection. NSD samples were taken 1 1/2 years after collection.

Table 12. Newman Sound piston core data: mean and standard deviations on data from samples taken 3 weeks and 1 1/2 years after core collection.

Sample set	$\delta^{15}N$ mean ± σ (°/oo)	$\delta^{13}C$ mean ± σ (°/oo)	%C mean ± σ	%N mean ± σ	C/N mean ± σ
NS1	7.4 ± 0.3	-20.6 ± 0.1	3.78 ± 1.12	0.63 ± 0.25	7.3 ± 1.4
NSD	7.5 ± 0.4	-20.4 ± 0.2	4.12 ± 1.45	0.61 ± 0.41	9.4 ± 2.9

Table 13. Surface water seston data for all research cruises.

Stn.	Depth (m)	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	mgC/l	mgN/l	C/N	TSM (mg/l)	Date (m/d/yr)
WB1	3	10.1	-24.3	0.042	0.005	9.1	*	11/17/86
WB1	4	11.7	-29.7	0.029	0.012	2.8	2.125	5/27/87
WB1	5	8.8	-25.6	0.033	0.010	3.8	1.022	8/15/87
WB7	3	8.5	-24.3	0.046	0.006	8.7	*	11/17/86
WB6	5	9.2	-21.7	0.095	0.013	8.3	0.325	5/27/87
WB6	5	7.3	-24.4	0.042	0.009	5.8	0.240	8/15/87
SB4	3	7.9	-23.3	0.042	0.006	8.7	*	11/17/86
SB2	6	8.5	-25.1	0.053	0.010	6.0	0.179	5/26/87
SB2	5	9.0	-26.3	0.038	0.010	4.3	1.556	8/15/87
GB1	3	9.0	-24.2	0.036	0.006	7.4	*	11/18/86
GB3	5	8.7	-24.5	0.076	0.011	8.3	0.244	8/14/87
HB1	2	8.2	-23.8	0.029	0.005	6.5	*	11/18/86
HB3	4	6.8	-22.5	0.098	0.012	9.2	0.350	5/26/87
ND2	2	5.0	-23.3	0.042	0.005	9.3	*	11/18/86
ND2	5	6.1	-24.1	0.070	0.010	8.1	0.643	5/26/87
ND2	5	7.4	-27.7	0.033	0.009	4.3	0.220	8/14/87
EX6	4	3.8	-23.6	0.037	0.010	4.2	*	11/19/86
EX6	5	5.7	-23.3	0.111	0.014	9.2	0.474	5/25/87
EX6	5	7.2	-23.5	0.062	0.013	5.7	1.089	8/14/87
EX4	5	6.3	-23.5	0.130	0.014	10.8	0.711	5/25/87
EX4	5	8.6	-24.5	0.068	0.013	6.0	0.844	8/14/87
EX3	5	2.7	-23.2	0.080	0.011	8.7	0.737	5/25/87
EX3	5	6.9	-23.0	0.080	0.013	7.5	0.088	8/13/87
EX2	5	3.6	-23.7	0.104	0.010	12.6	1.622	5/25/87
EX2	5	7.0	-24.8	0.095	0.015	7.4	1.100	8/13/87
EX1	6	4.2	-22.5	0.148	0.016	10.6	0.730	5/25/87
BB1	5	6.8	-24.2	0.100	0.011	10.2	0.395	5/24/87
NS1	4	9.3	-23.7	0.104	0.012	9.7	*	11/21/86

* Data was not collected.

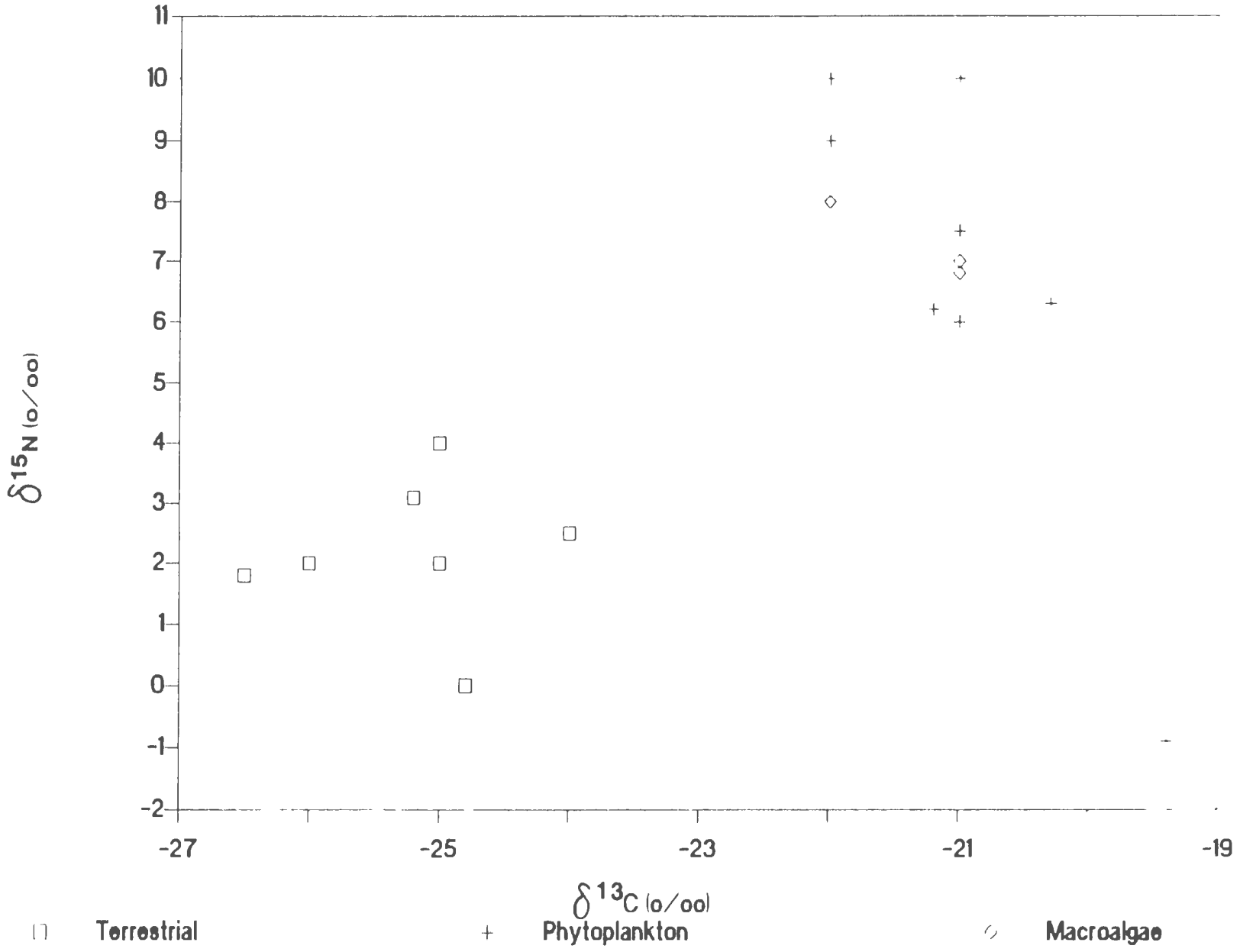
Table 13. Continued.

Stn.	Depth (m)	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (°/oo)	mgC/l	mgN/l	C/N	TSM (mg/l)	Date (m/d/yr)
TB6	5	6.1	-25.6	0.174	0.014	15.0	0.800	5/23/87
TB6	5	8.8	-24.7	0.037	0.010	4.4	1.156	8/12/87
TB5	5	6.4	-23.5	0.176	0.012	17.0	0.500	5/23/87
TB5	5	8.4	-25.7	0.031	0.009	3.9	1.933	8/12/87
RS1	5	9.7	-23.6	0.043	0.009	5.5	0.200	8/12/87

Table 14. Isotopic composition and C/N of endmembers and surficial grab sediments of northern Newfoundland.

Endmember or grab	$\delta^{15}N$ (°/oo)	$\delta^{13}C$ (o/oo)	C/N	Description
Phytoplankton Endmember	8.2	-24.6	6.5	Marine seston excluding samples with a terrestrial or macroalgae influence
Terrestrial	2.2 to 5.1	-25.5 to -24.9	12.3 to 8.1	The two values in each set are; the average for the Exploits River and the average of terrestrial seston excluding Exploits River
Macroalgae Endmember	4.6	-20.3	9.2	L. solidungula
Average of Surficial Sediments from grabs	7.6	-21.8	6.7	Average of samples from all marine stations

Figure 1. Carbon and nitrogen isotopic composition of organic matter sources contributing to marine sediments from various locations.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10
9
8
7
6
5
4
3
2
1
0
-1
-2
-27
-25
-23
-21
-19
δ15N (o/oo)
δ13C (o/oo)
Terrestrial
Phytoplankton
Macroalgae

Figure 2. Cycling of particulate organic carbon in the sea and associated isotopic effects.

DOM: dissolved organic matter
POMsink: sinking particular organic matter
1: dissolution, degradation
2: oxidative degradation
3: aggregation
4: dissolution
5: resuspension

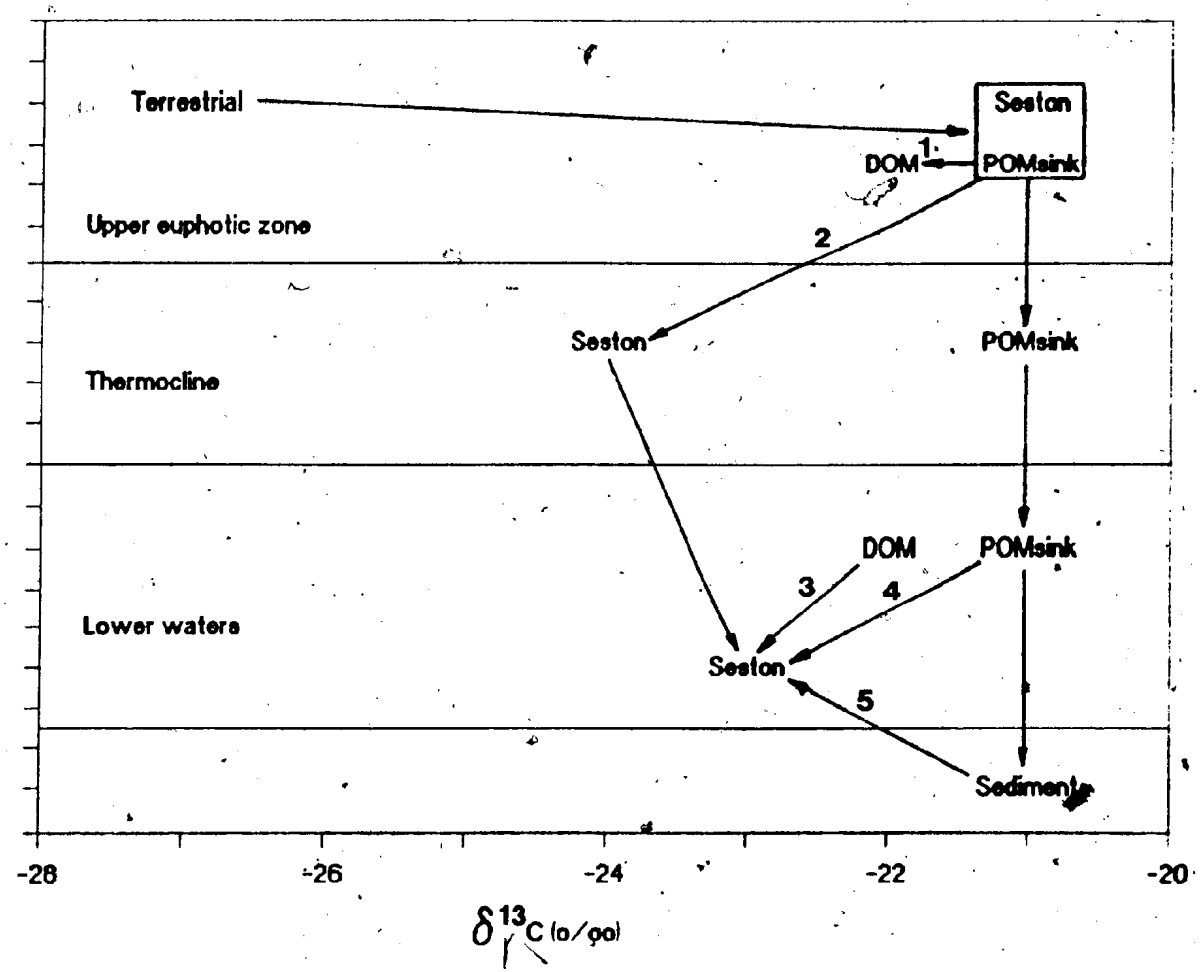
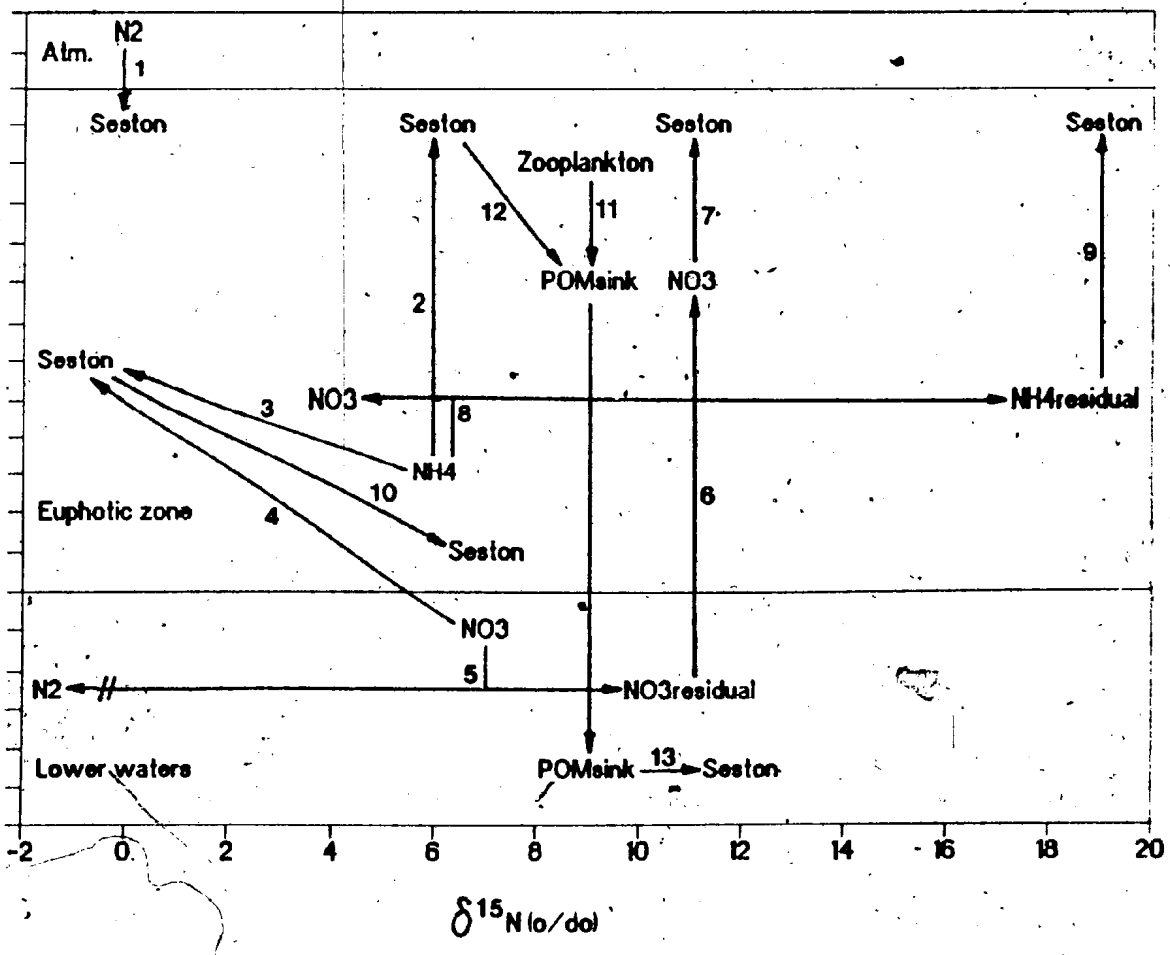

Terrestrial
Seston
DOM
POMsink
1
Upper euphotic zone
2
Seston
POMsink
Thermocline
DOM
POMsink
3
4
Lower waters
Seston
5
Sediments
-28
-26
-24
-22
-20
δ13C (o/oo)

Figure 3. Cycling of particulate organic nitrogen in the sea and associated isotopic effects.

POMsink: sinking particular organic matter
1: nitrogen fixation
2: ammonium assimilation, rate limiting
3: ammonium assimilation, non rate limiting
4: nitrate assimilation, non rate limiting
5: denitrification
6: advection
7: nitrate assimilation, rate limiting
8: nitrification
9: ammonium assimilation, rate limiting
10: oxidative degredation
11: contribution of zooplankton detritus
12: contribution of fecal matter
13: disaggregation


Atm.
N2
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Seston
Seston
Zooplankton
Seston
Seston
12
11
7
9
POMsink
NO3
2
Seston
3
NO3
8
NH4residual
NH4
10
6
Euphotic zone
4
Seston
NO3
5
N2
NO3residual
Lower waters
POMsink
13
Seston
-2
0
2
4
6
8
10
12
14
16
18
20
δ15N (o/oo)

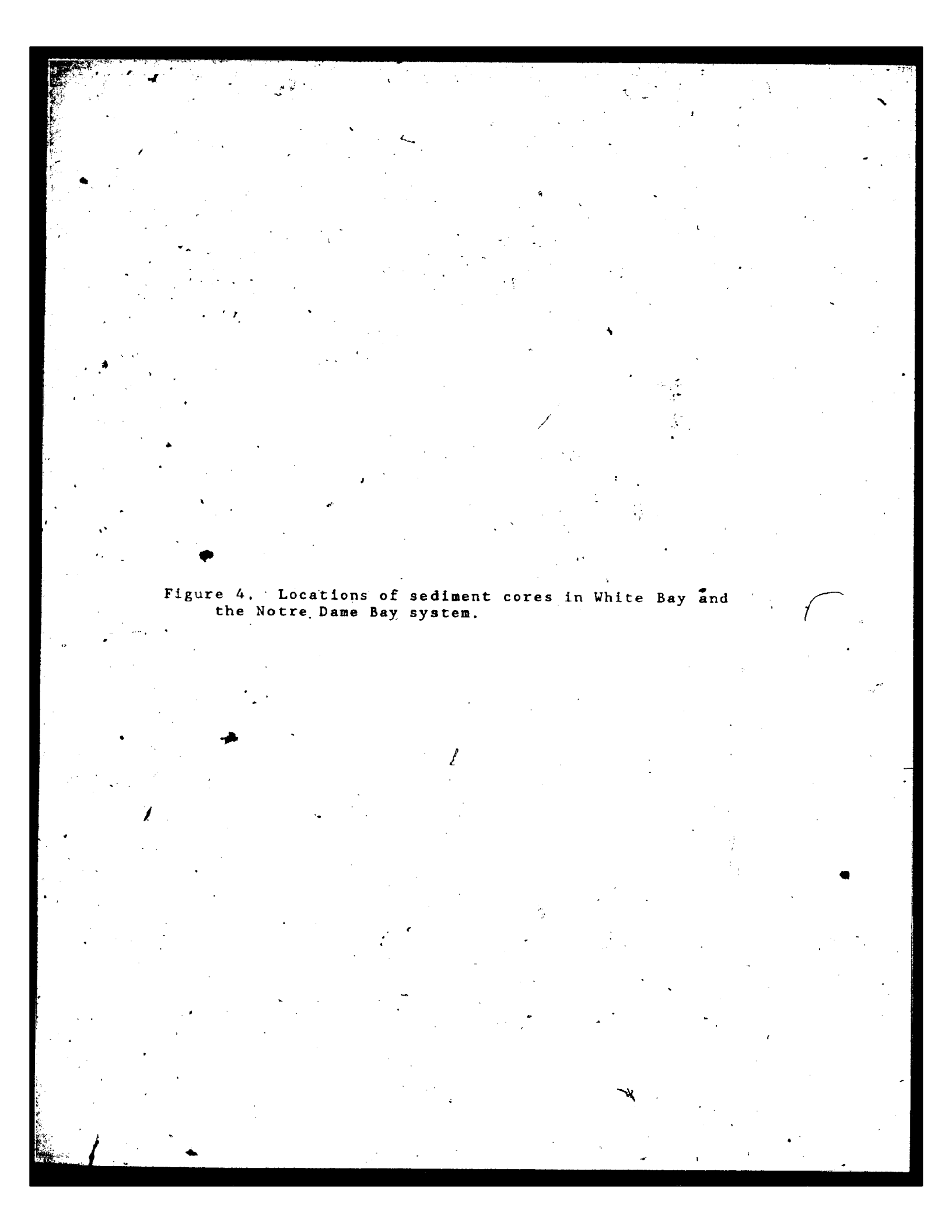
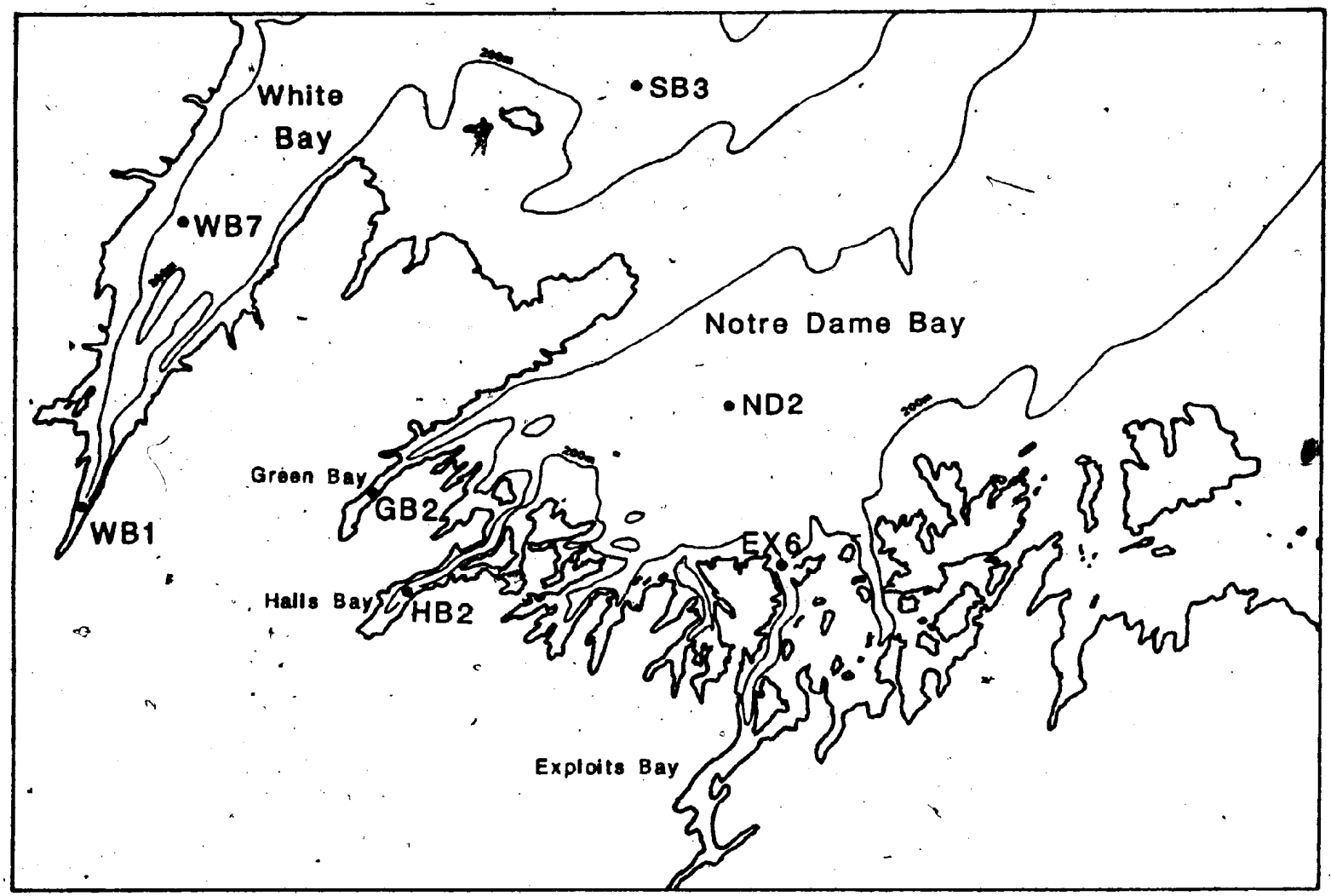


Figure 4. Locations of sediment cores in White Bay and the Notre Dame Bay system.


White
Bay
SB3
WB7
Notre Dame Bay
ND2
Green Bay
GB2
WB1
EX6
Halls Bay
HB2
Exploits Bay

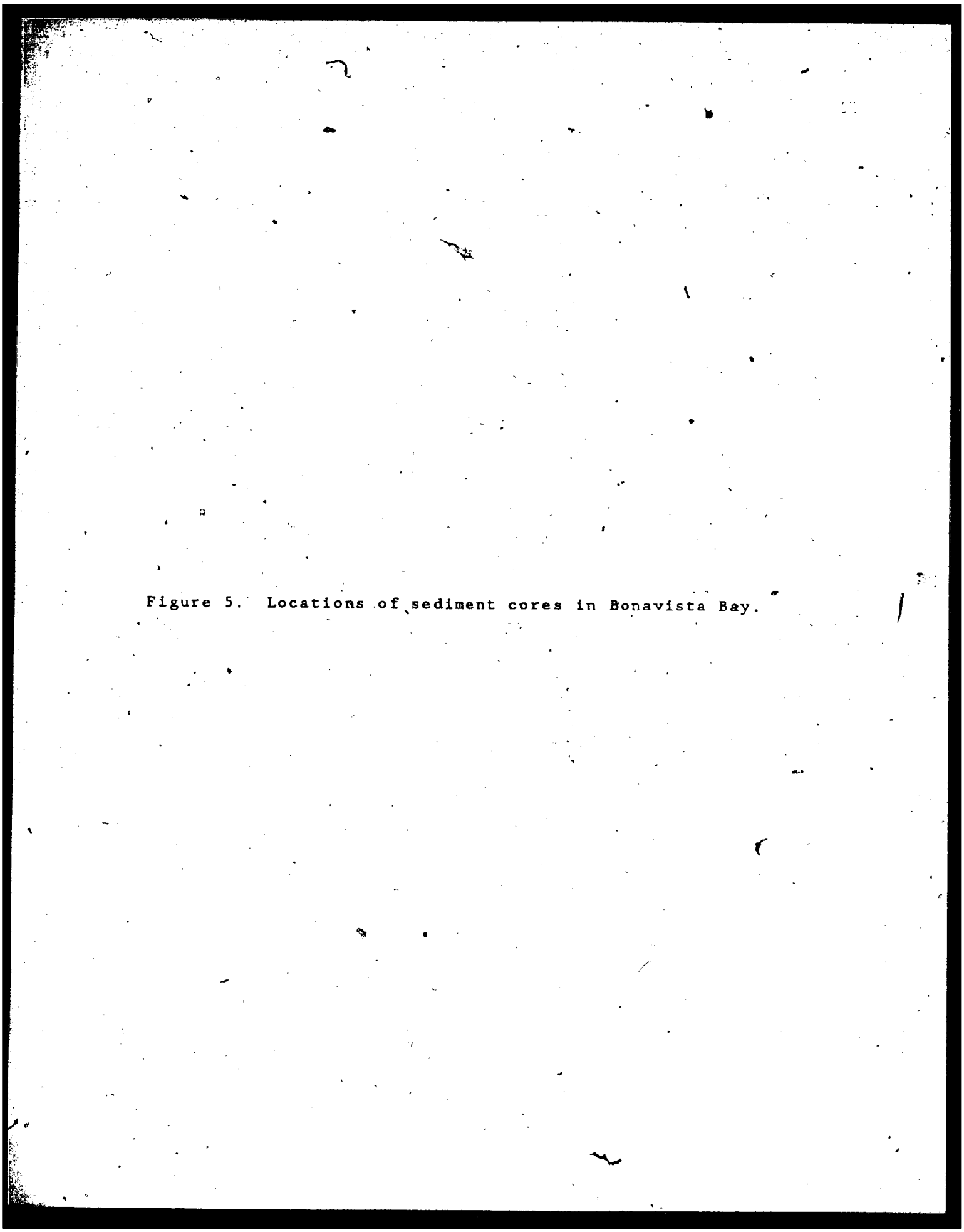
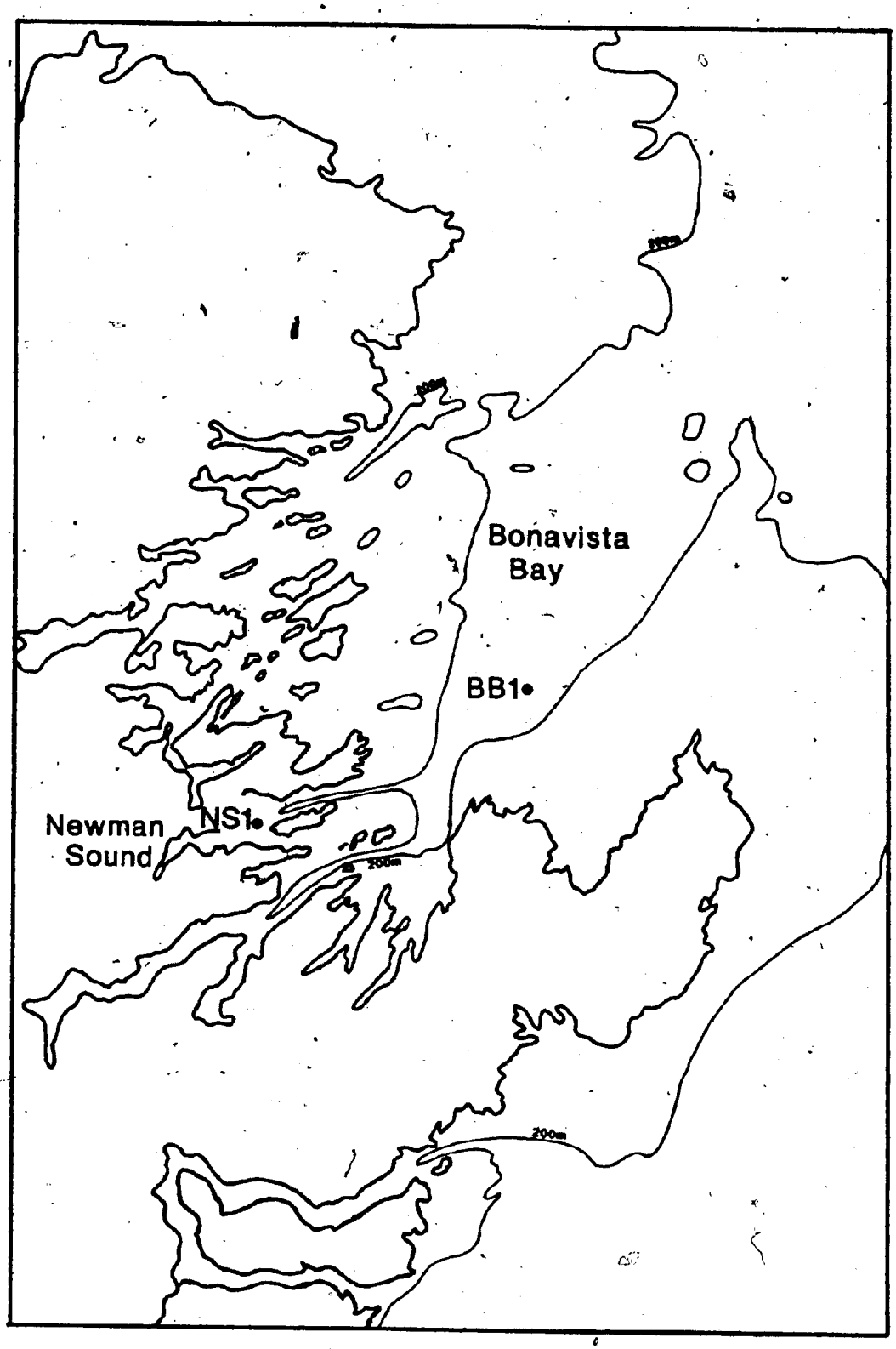


Figure 5. Locations of sediment cores in Bonavista Bay.


Bonavista
Bay
BB1
Newman
Sound
NS1
200m
200m

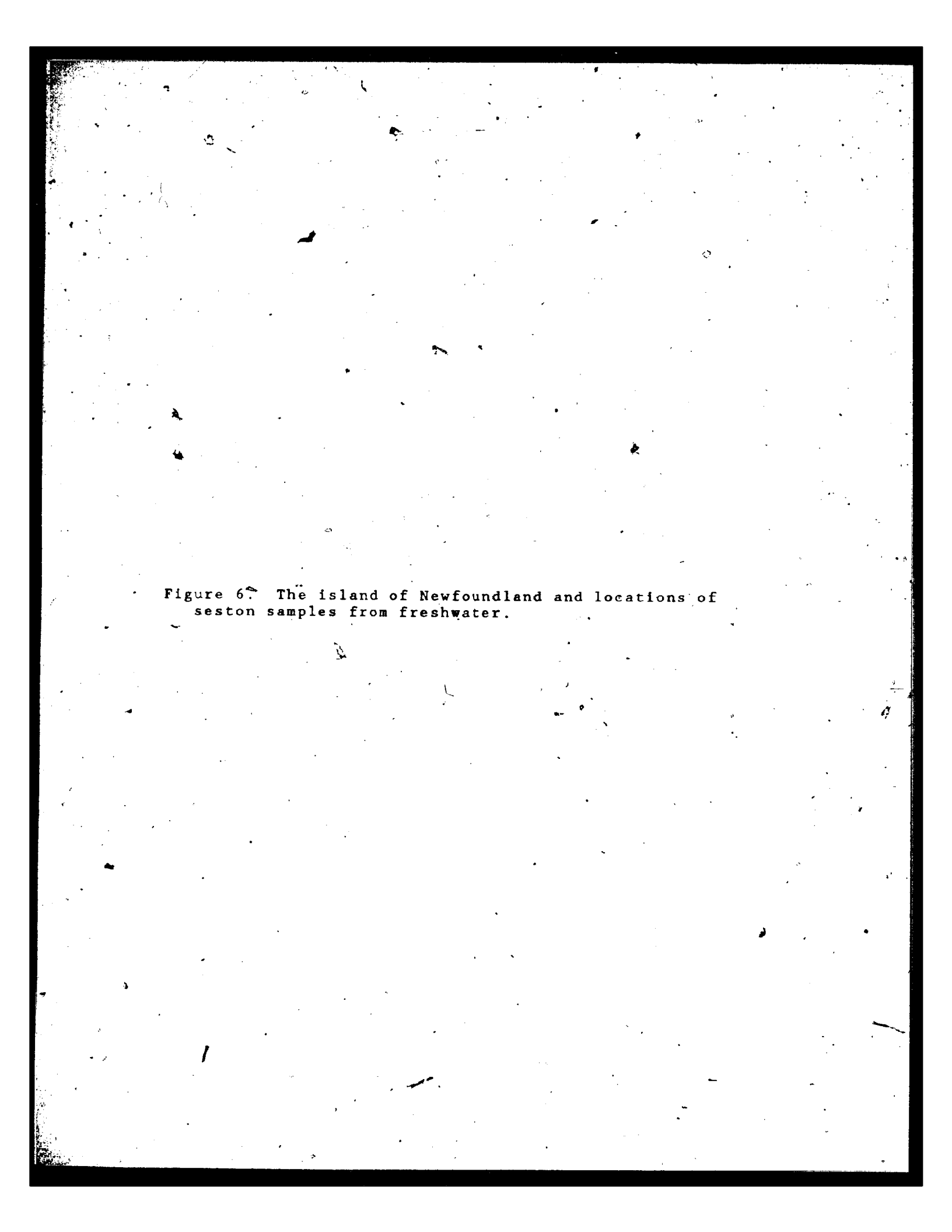
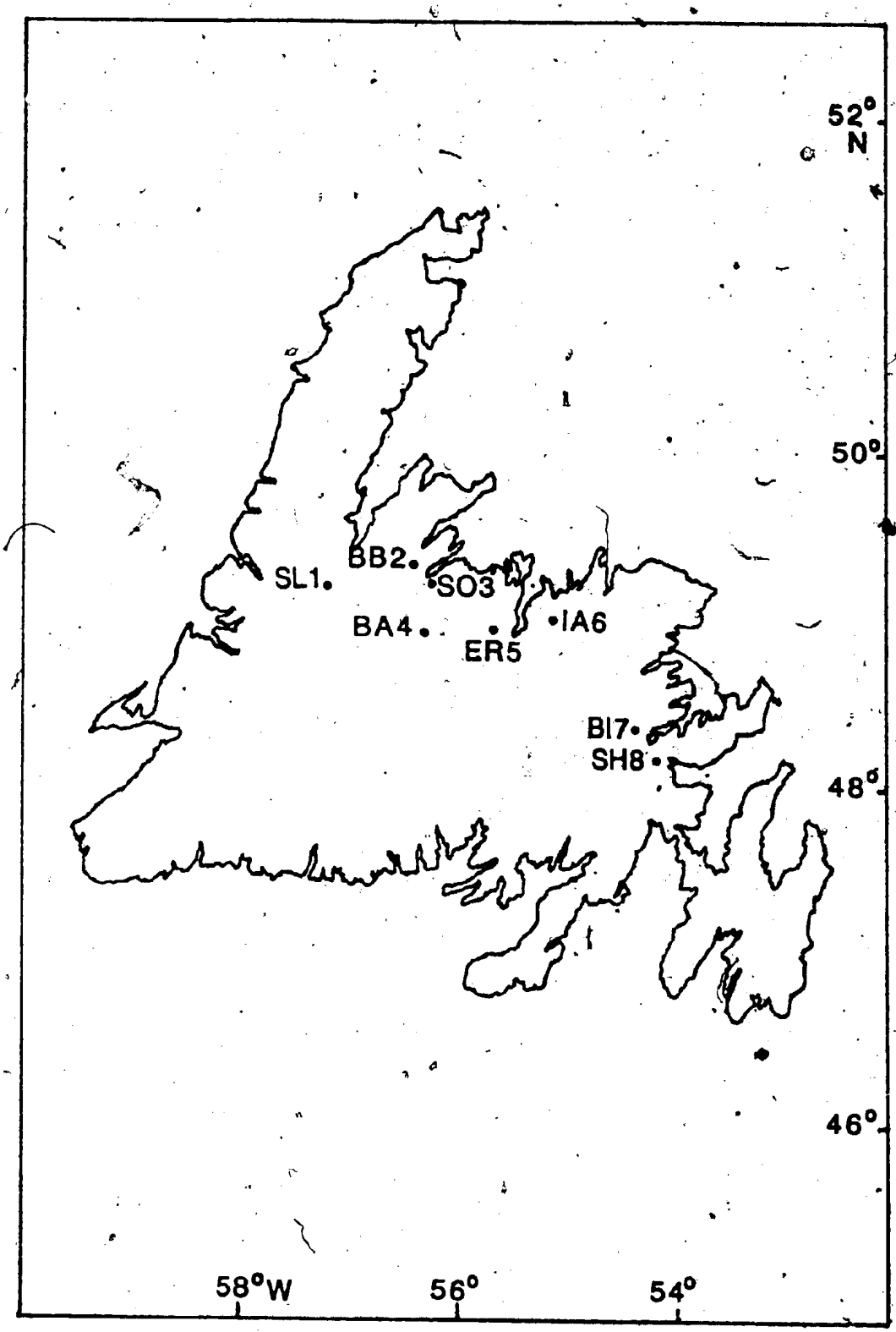


Figure 6. The island of Newfoundland and locations of seston samples from freshwater.


52°
N
50°
48°
46°
58°W
56°
54°
SL1
BB2
SO3
BA4
ER5
IA6
BI7
SH8

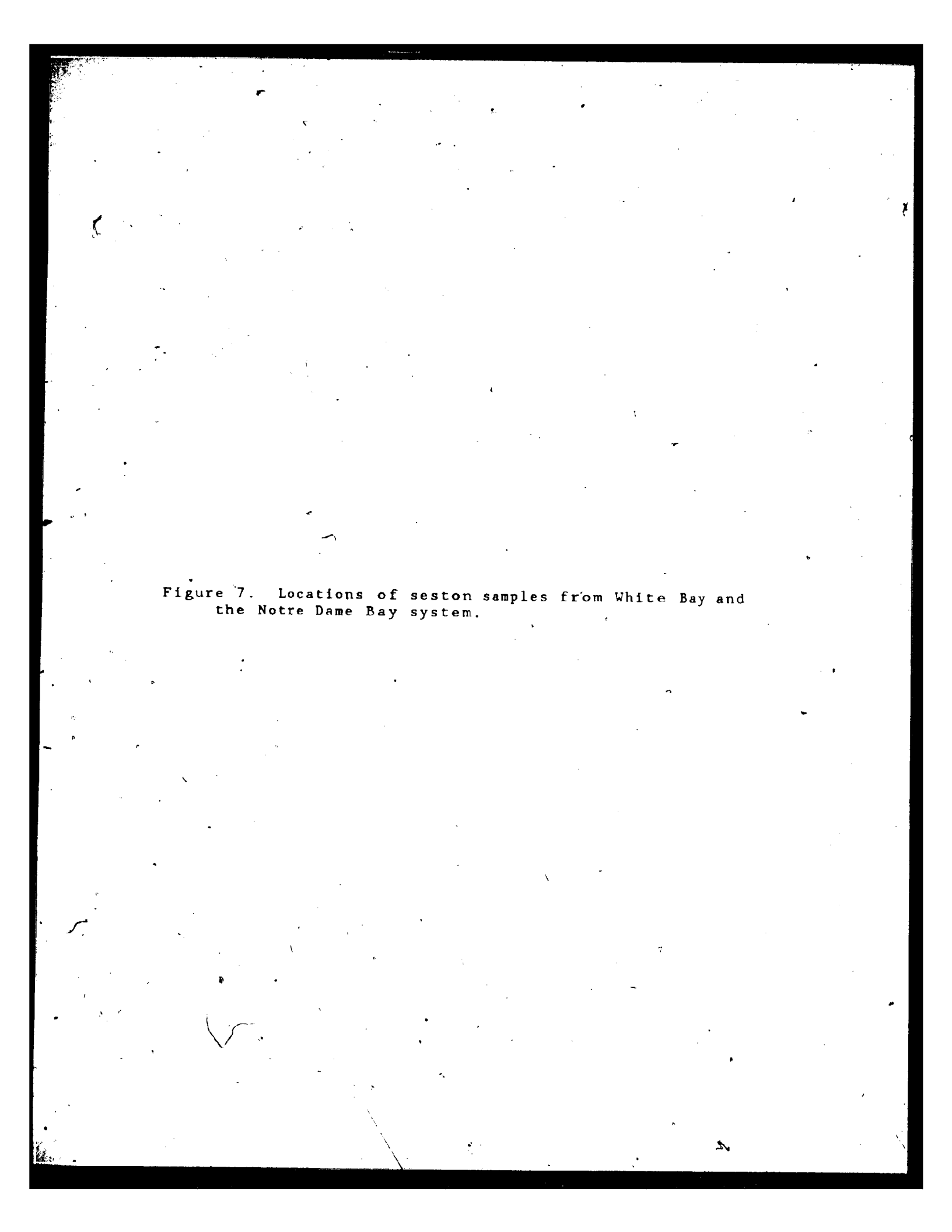


Figure 7. Locations of seston samples from White Bay and the Notre Dame Bay system.

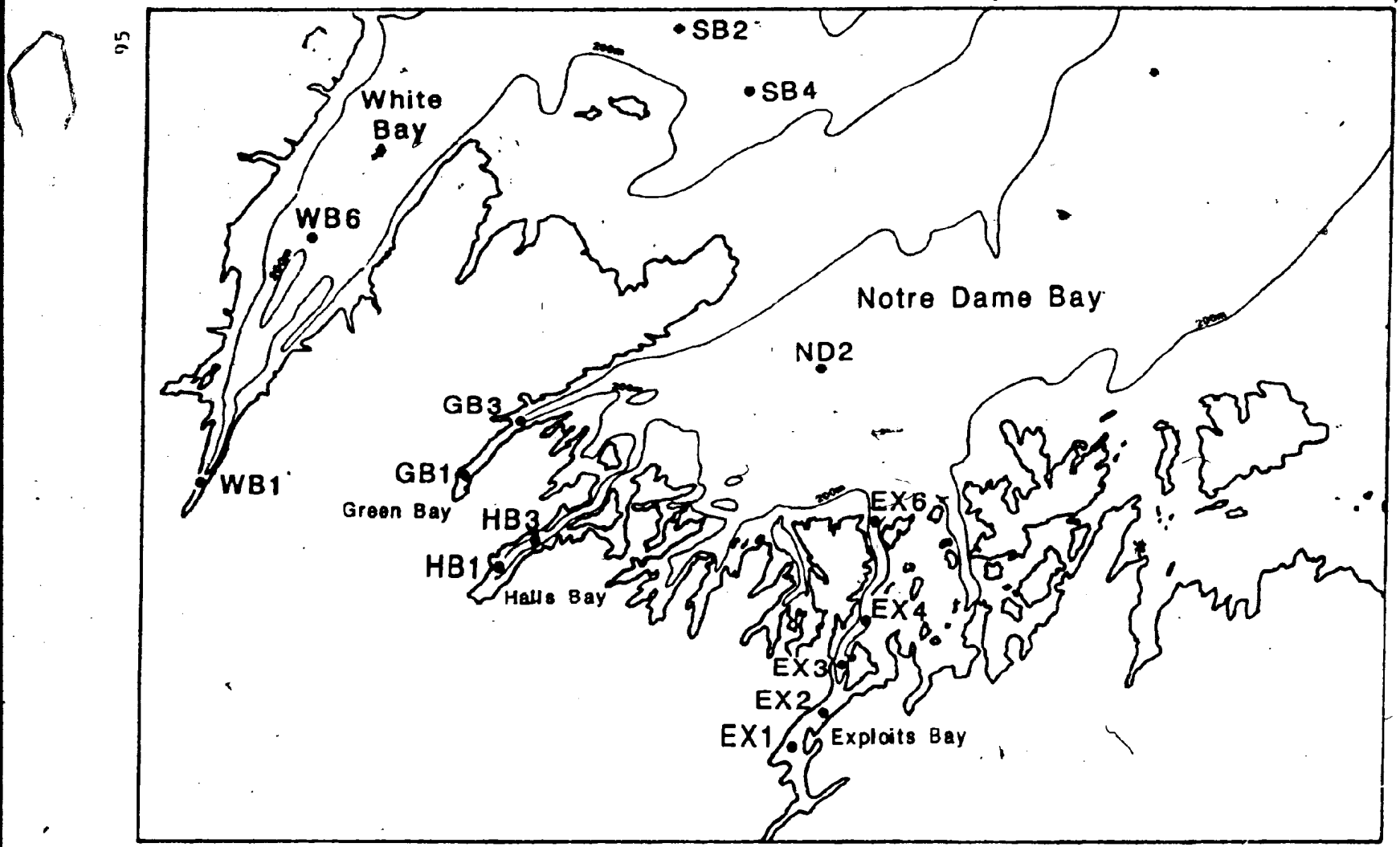
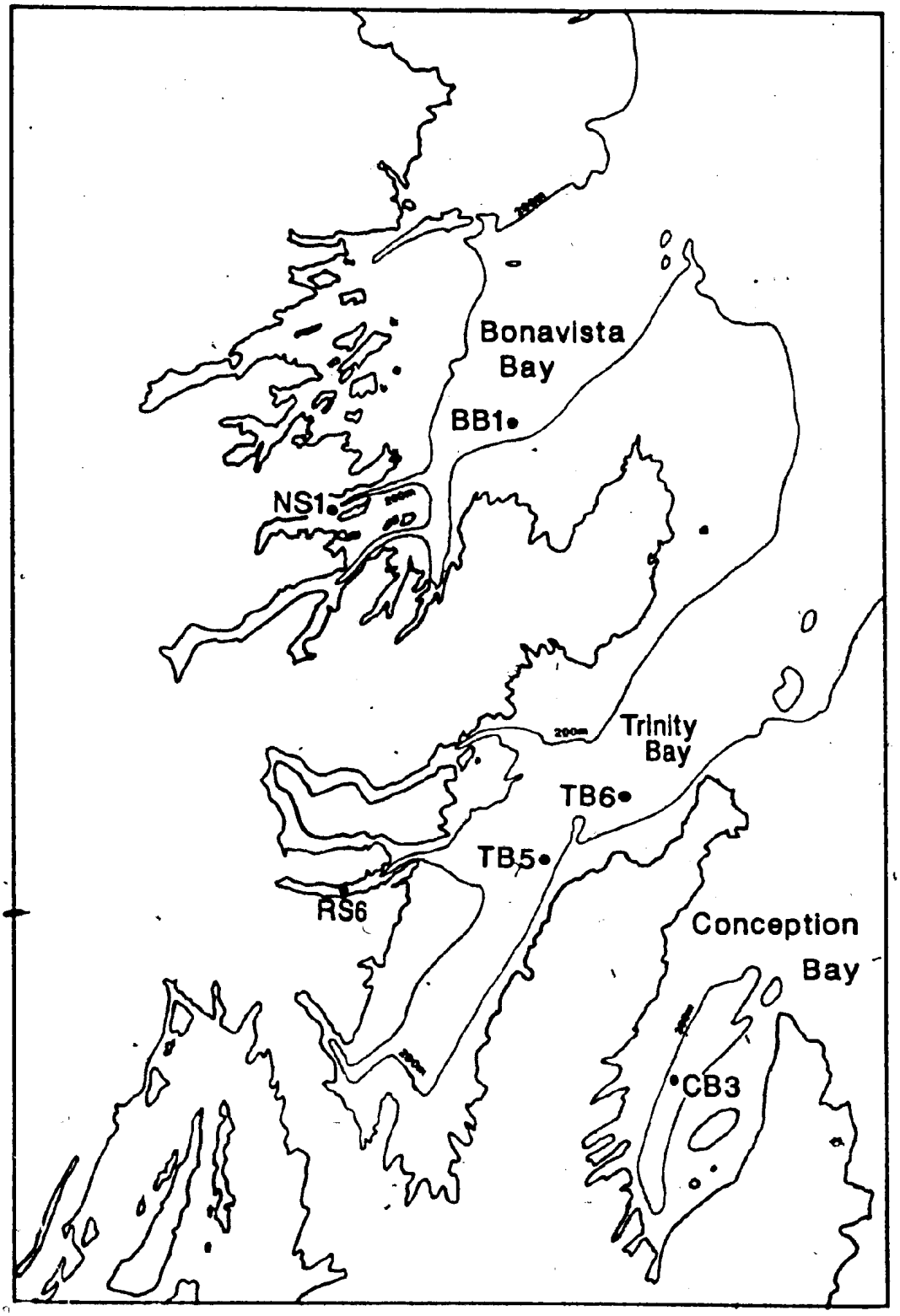

SB2
SB4
White Bay
WB6
Notre Dame Bay
ND2
GB3
GB1
WB1
Green Bay
HB3
HB1
Halls Bay
EX6
EX4
EX3
EX2
EX1
Exploits Bay

Figure 8. Location of seston samples from Bonavista, Trinity, and Conception Bays.


Bonavista
Bay
BB1
NS1
200m
Trinity
Bay
TB6
TB5
RS6
Conception
Bay
CB3

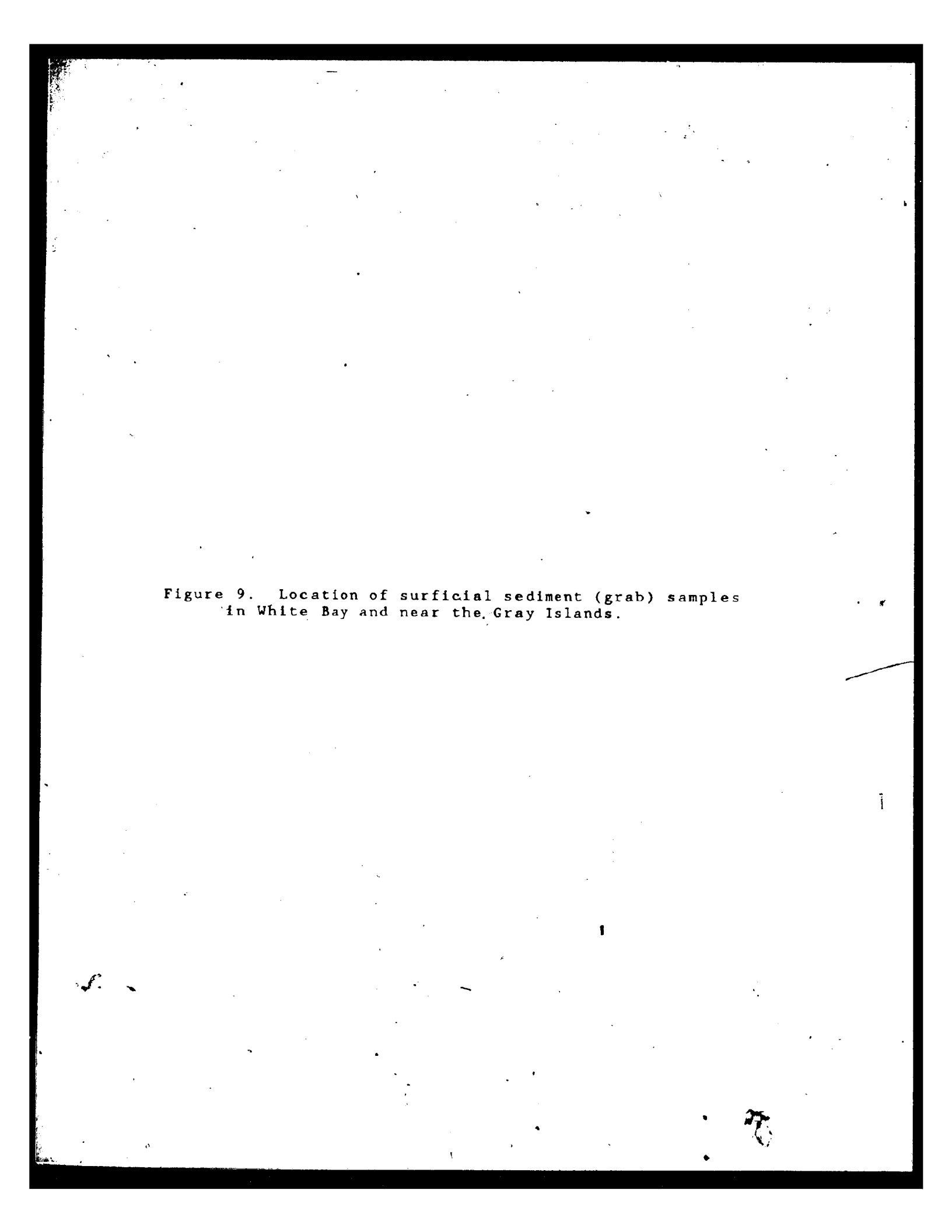


Figure 9. Location of surficial sediment (grab) samples in White Bay and near the Gray Islands.

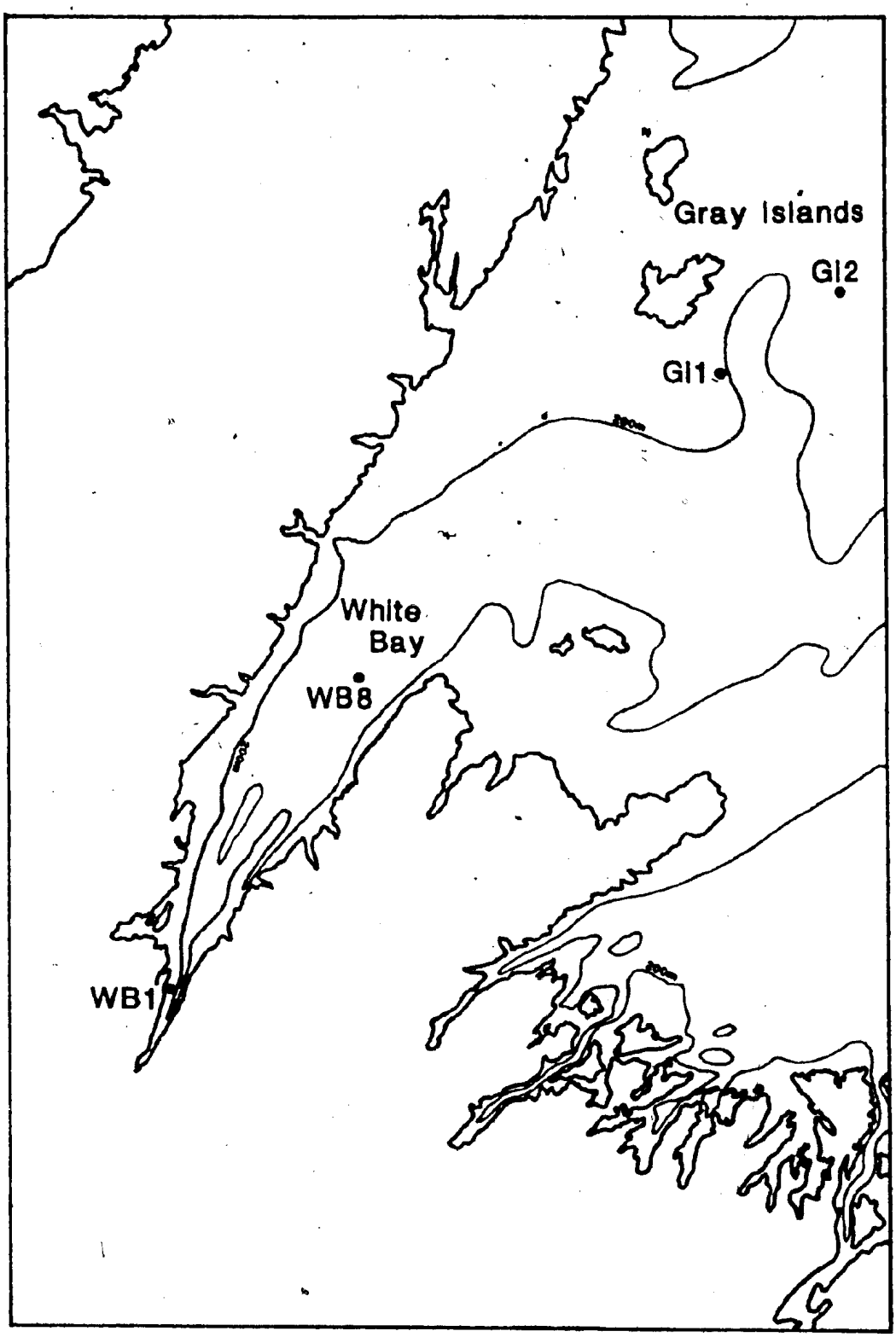
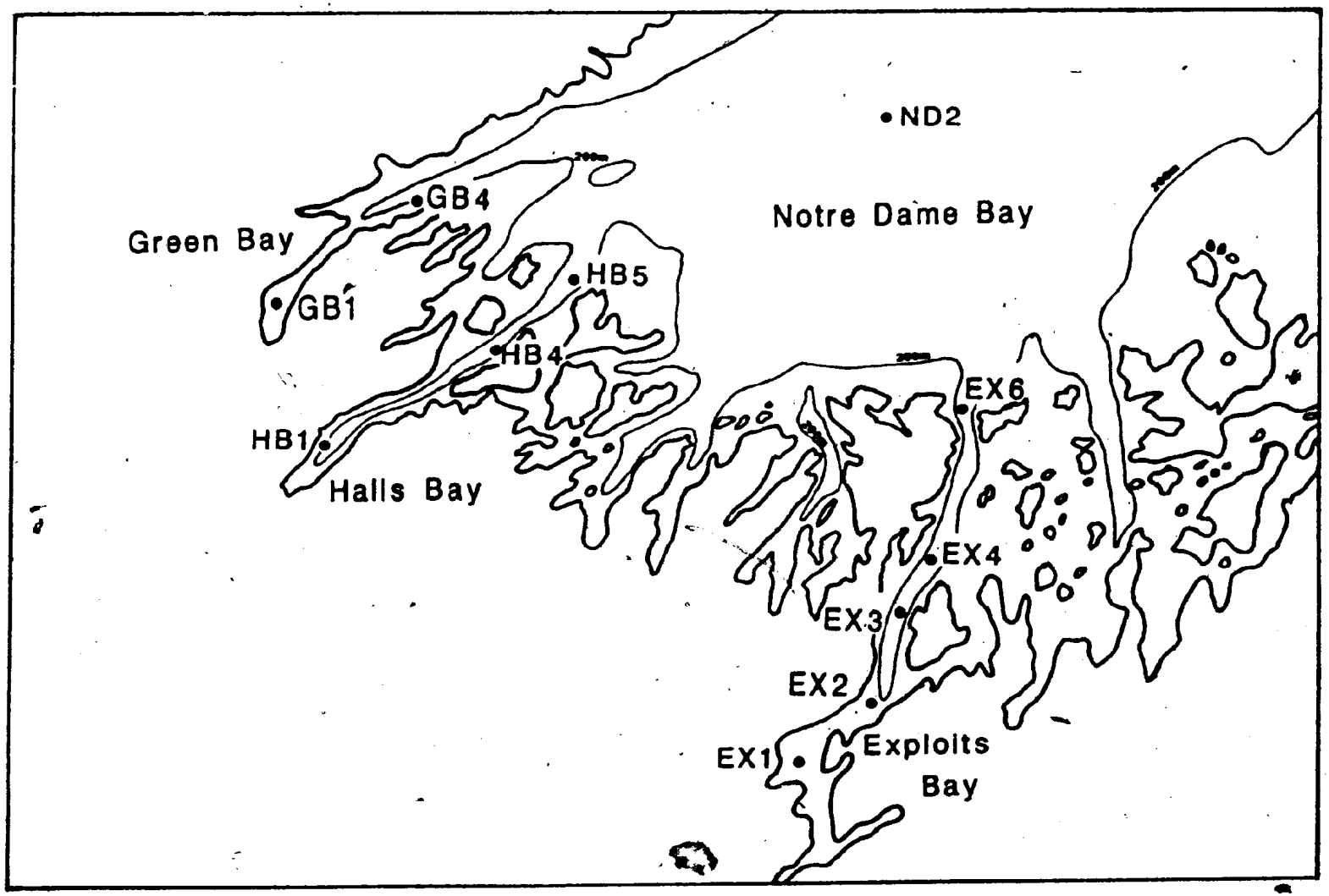

Gray Islands
Gl2
Gl1
White
Bay
WB8
WB1

Figure 10. Location of surficial sediment samples in the Notre Dame Bay system.


ND2
Notre Dame Bay
GB4
Green Bay
GB1
HB5
HB4
HB1
Halls Bay
EX6
EX4
EX3
EX2
EX1
Exploits
Bay

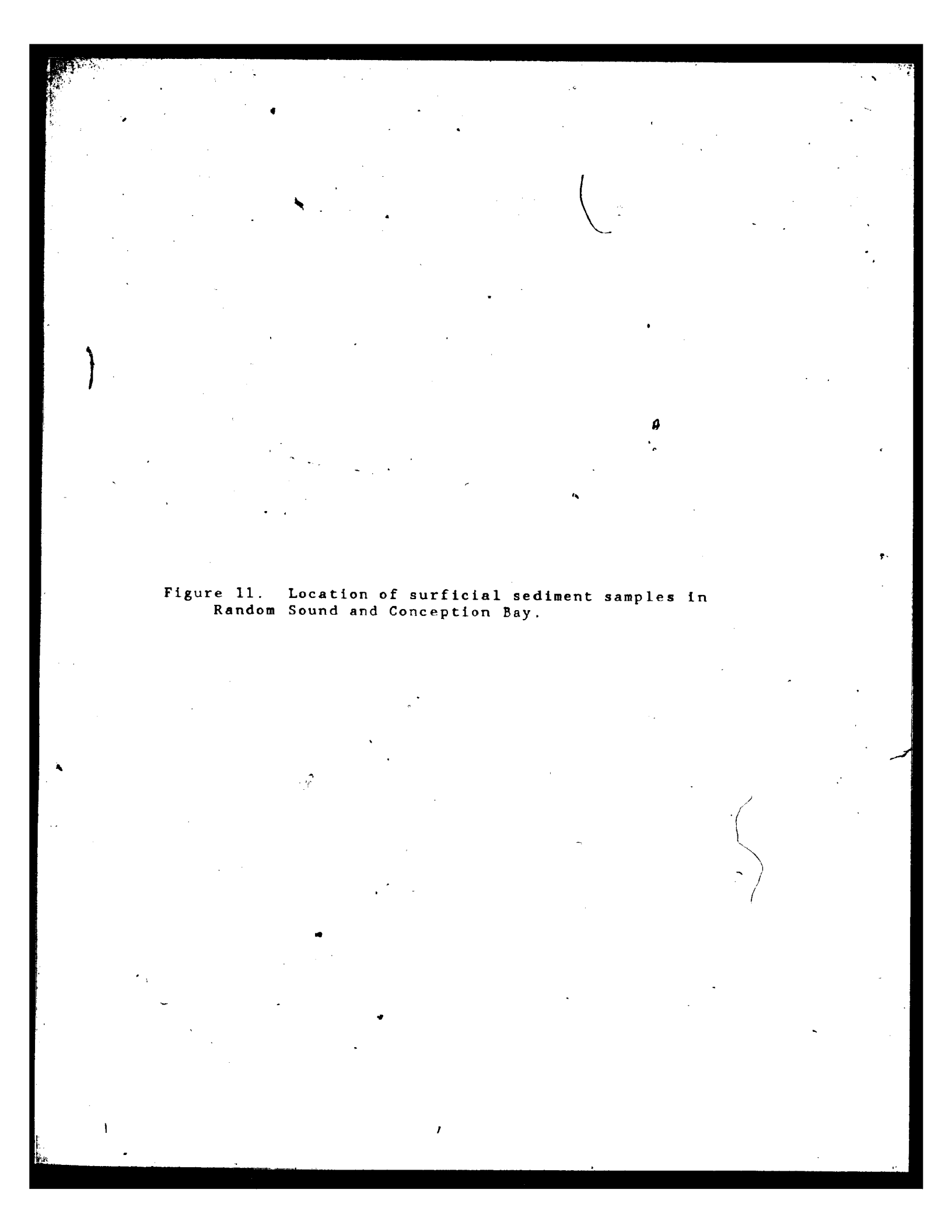


Figure 11. Location of surficial sediment samples in Random Sound and Conception Bay.

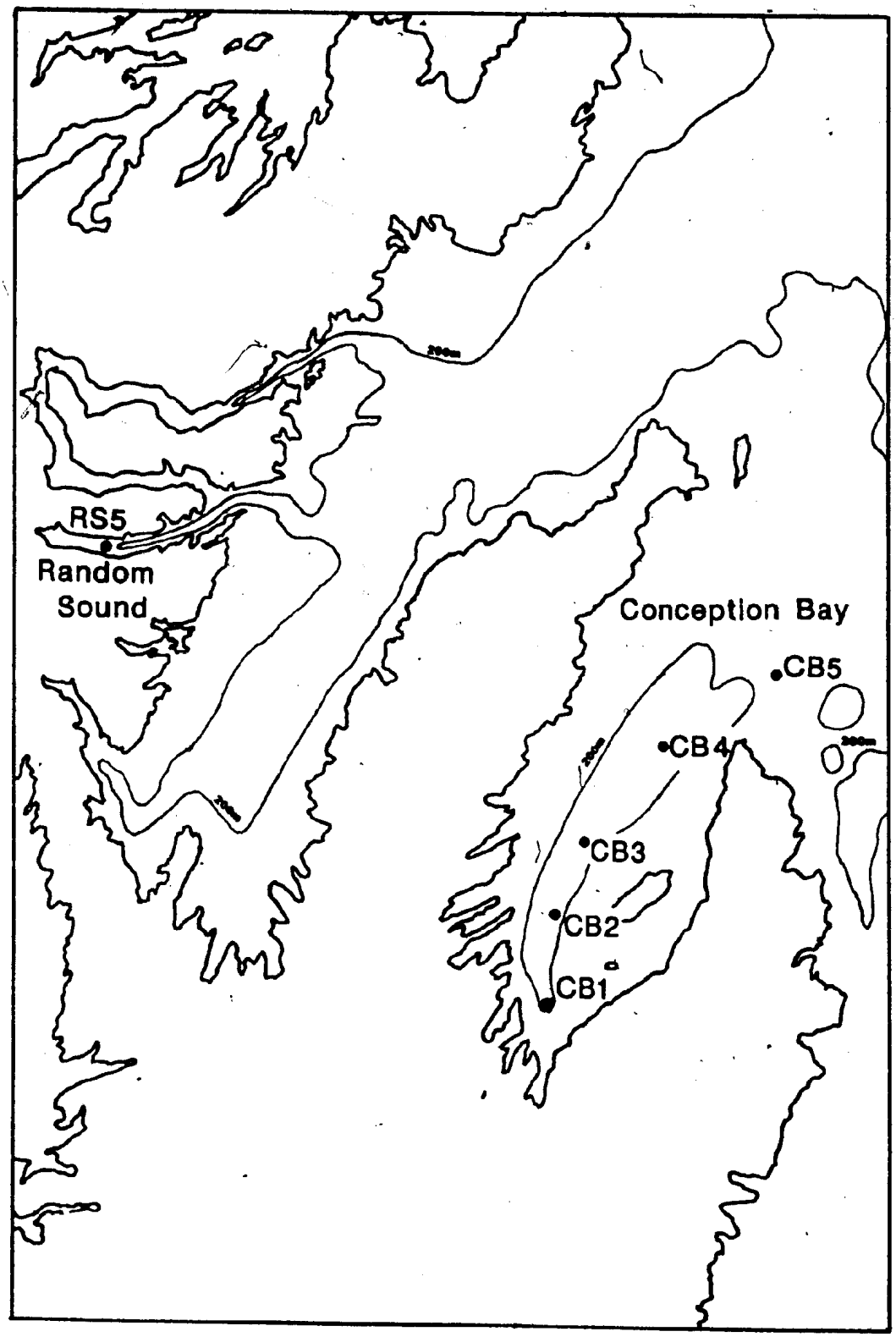

RS5
Random
Sound
Conception Bay
CB5
CB4
CB3
CB2
CB1

Figure 12. Carbon and nitrogen isotopic and elemental data on 15 samples taken from different locations on the same *Laminaria solidungula* alga.

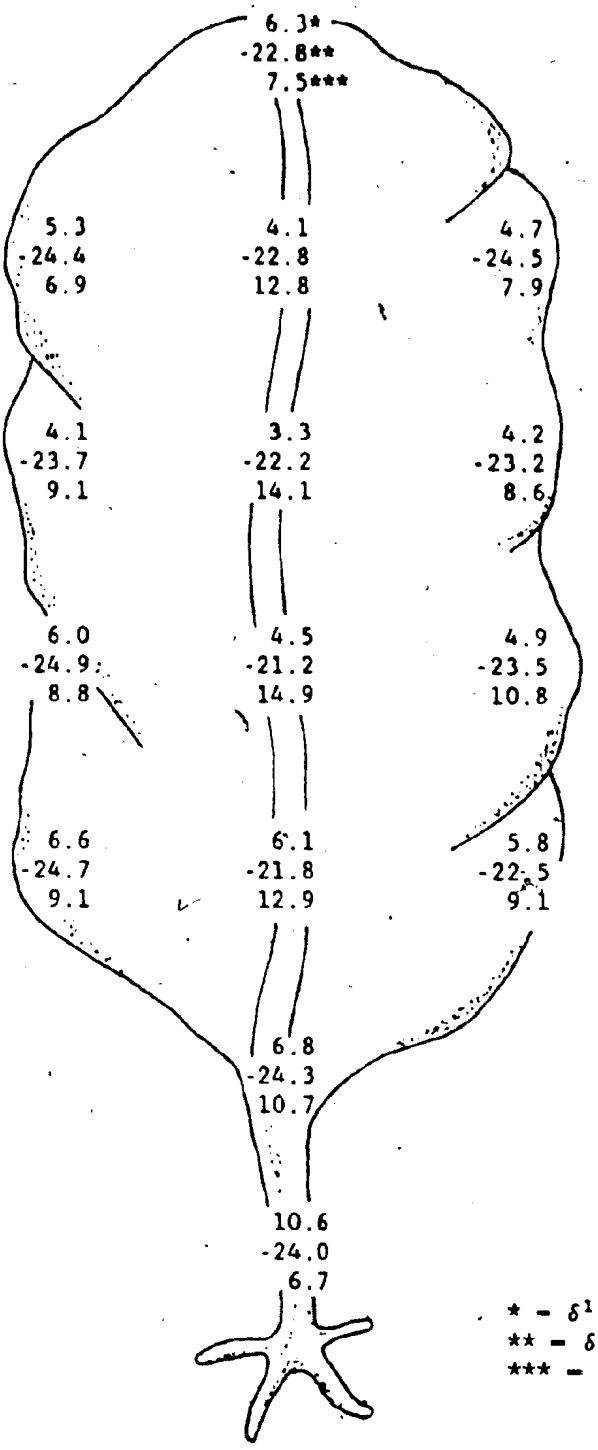
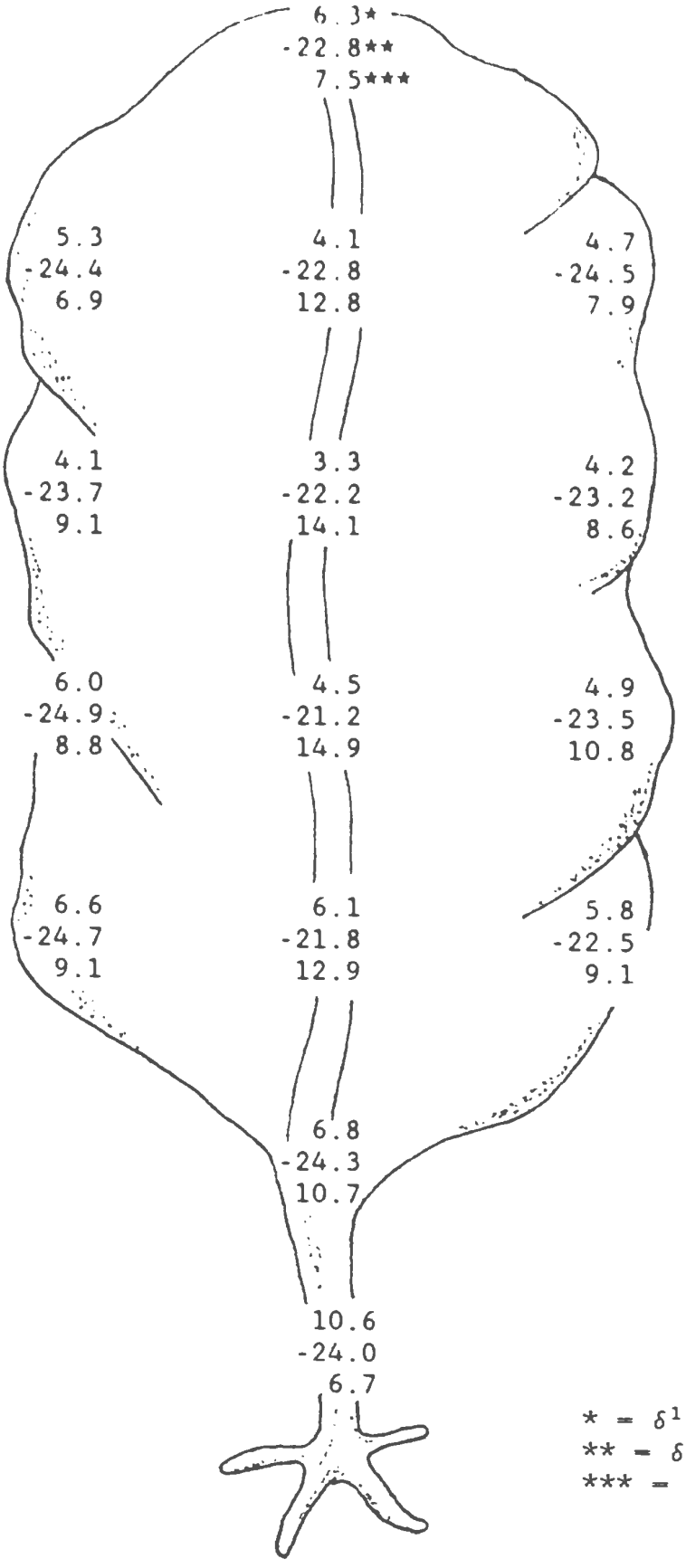

6.3*
-22.8**
7.5***
5.3
-24.4
6.9
4.1
-22.8
12.8
4.7
-24.5
7.9
4.1
-23.7
9.1
3.3
-22.2
14.1
4.2
-23.2
8.6
6.0
-24.9
8.8
4.5
-21.2
14.9
4.9
-23.5
10.8
6.6
-24.7
9.1
6.1
-21.8
12.9
5.8
-22.5
9.1
6.8
-24.3
10.7
10.6
-24.0
6.7
* - δ15N
** - δ13C
*** - C/N

Figure 13. Nitrogen isotopic composition of selected seston stations that showed depletions in ^{15}N in middle waters with respect to surface and bottom water samples.


6.3*
-22.8**
7.5***
5.3
-24.4
6.9
4.1
-22.8
12.8
4.7
-24.5
7.9
4.1
-23.7
9.1
3.3
-22.2
14.1
4.2
-23.2
8.6
6.0
-24.9
8.8
4.5
-21.2
14.9
4.9
-23.5
10.8
6.6
-24.7
9.1
6.1
-21.8
12.9
5.8
-22.5
9.1
6.8
-24.3
10.7
10.6
-24.0
6.7
* = δ15N
** = δ13C
*** = C/N

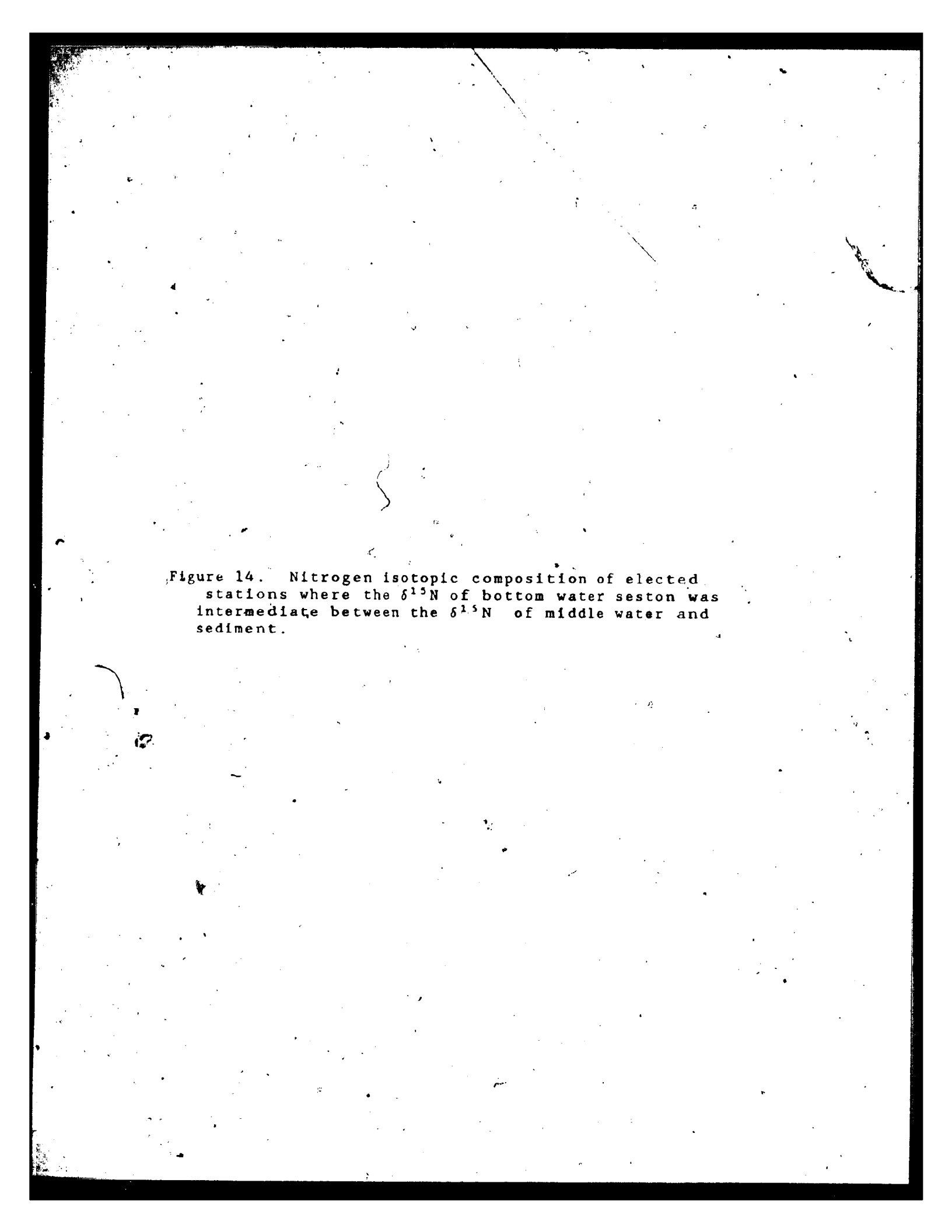


Figure 14. Nitrogen isotopic composition of elected stations where the $\delta^{15}N$ of bottom water seston was intermediate between the $\delta^{15}N$ of middle water and sediment.

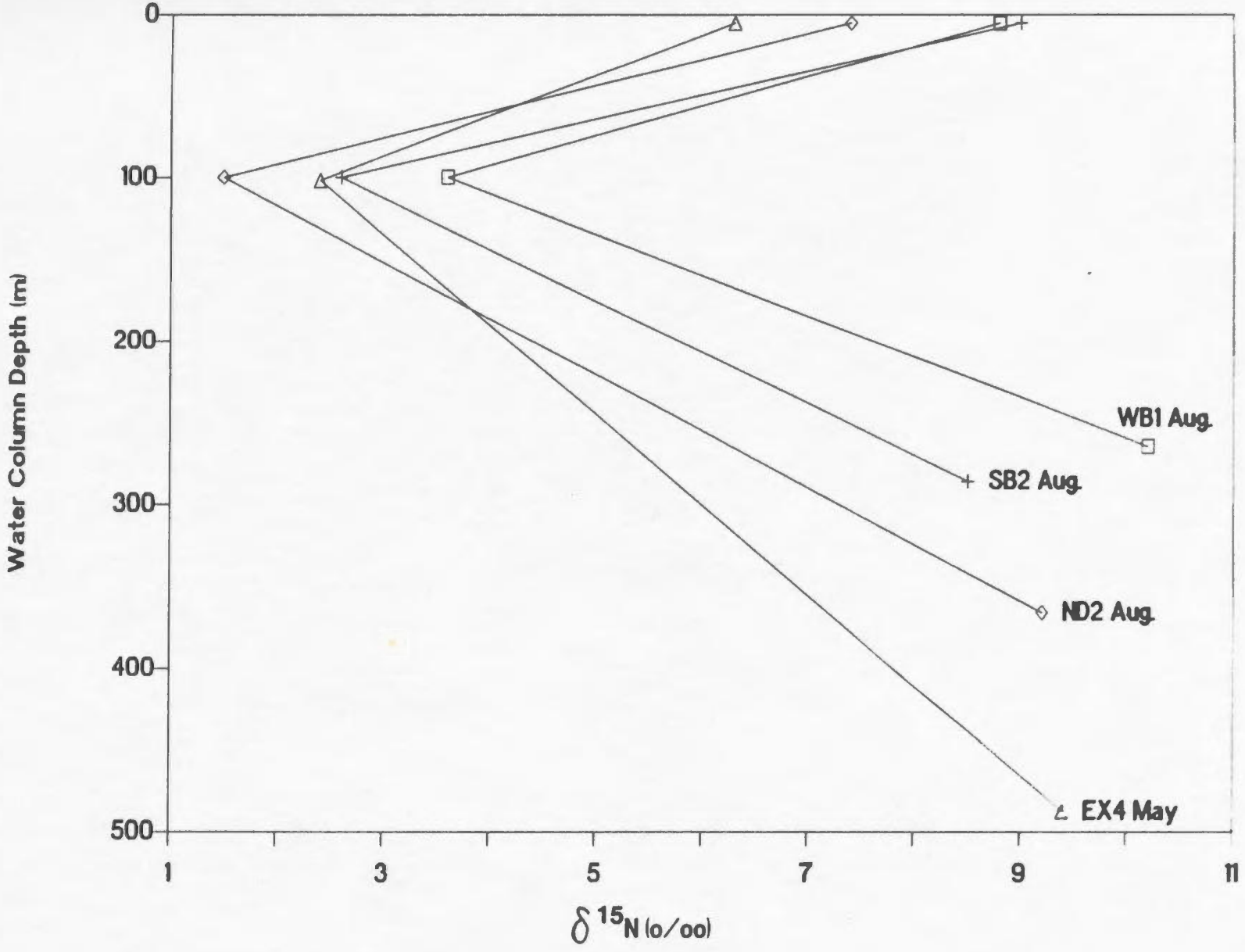

0
100
200
300
400
500
Water Column Depth (m)
1
3
5
7
9
11
δ 15N (o/oo)
WB1 Aug.
SB2 Aug.
ND2 Aug.
EX4 May

Figure 15. Nitrogen isotopic composition of selected seston stations which showed increasing $\delta^{15}N$ values with increasing depth in the water column.

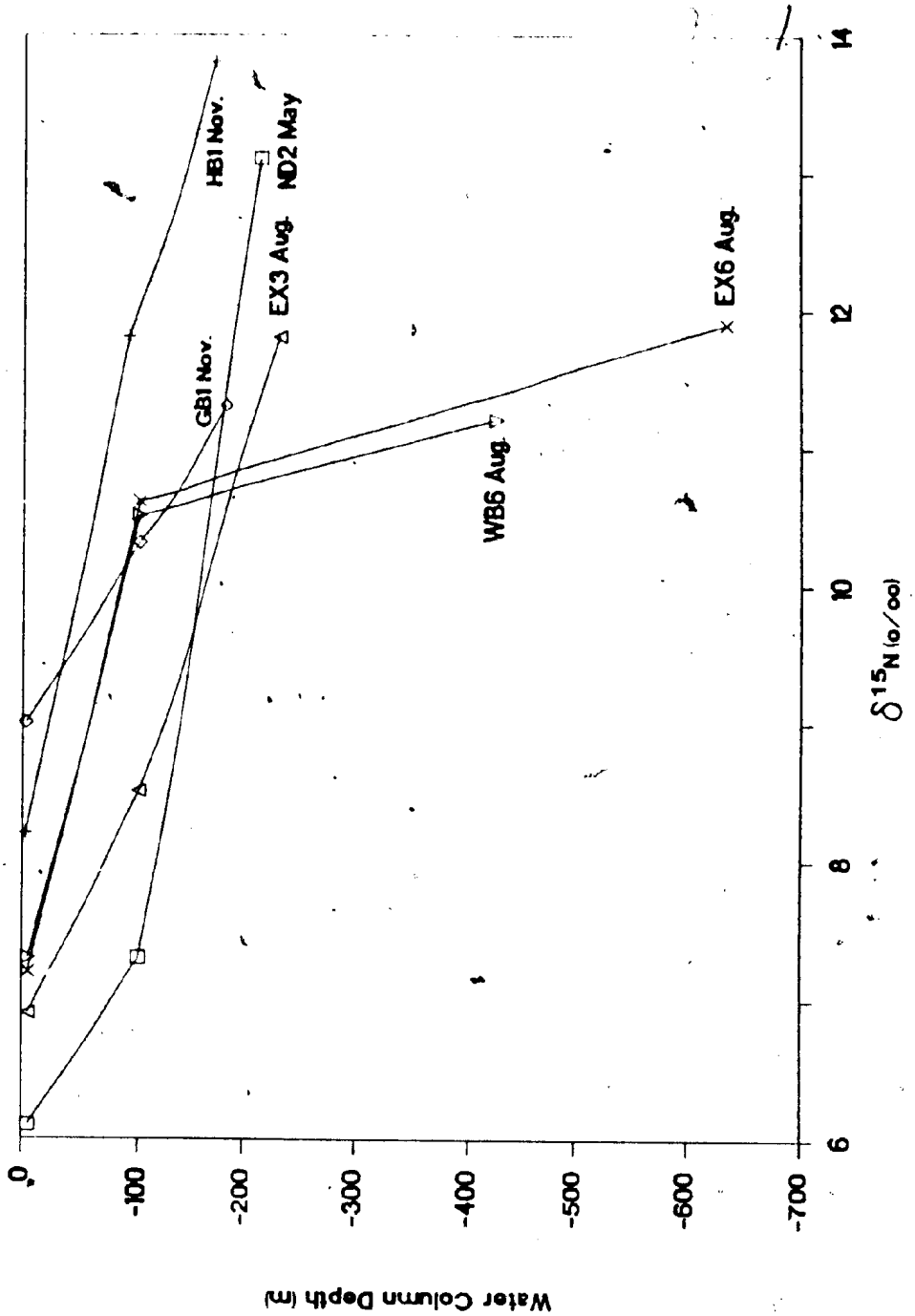

HB1 Nov.
ND2 May
GB1 Nov.
EX3 Aug.
EX6 Aug.
WB6 Aug.
0
-100
-200
-300
-400
-500
-600
-700
6
8
10
12
14
Water Column Depth (m)
δ15N (o/oo)

Figure 16. Carbon isotopic composition of selected stations where the $\delta^{13}C$ of bottom water seston was intermediate between the $\delta^{13}C$ of middle water and sediment values.

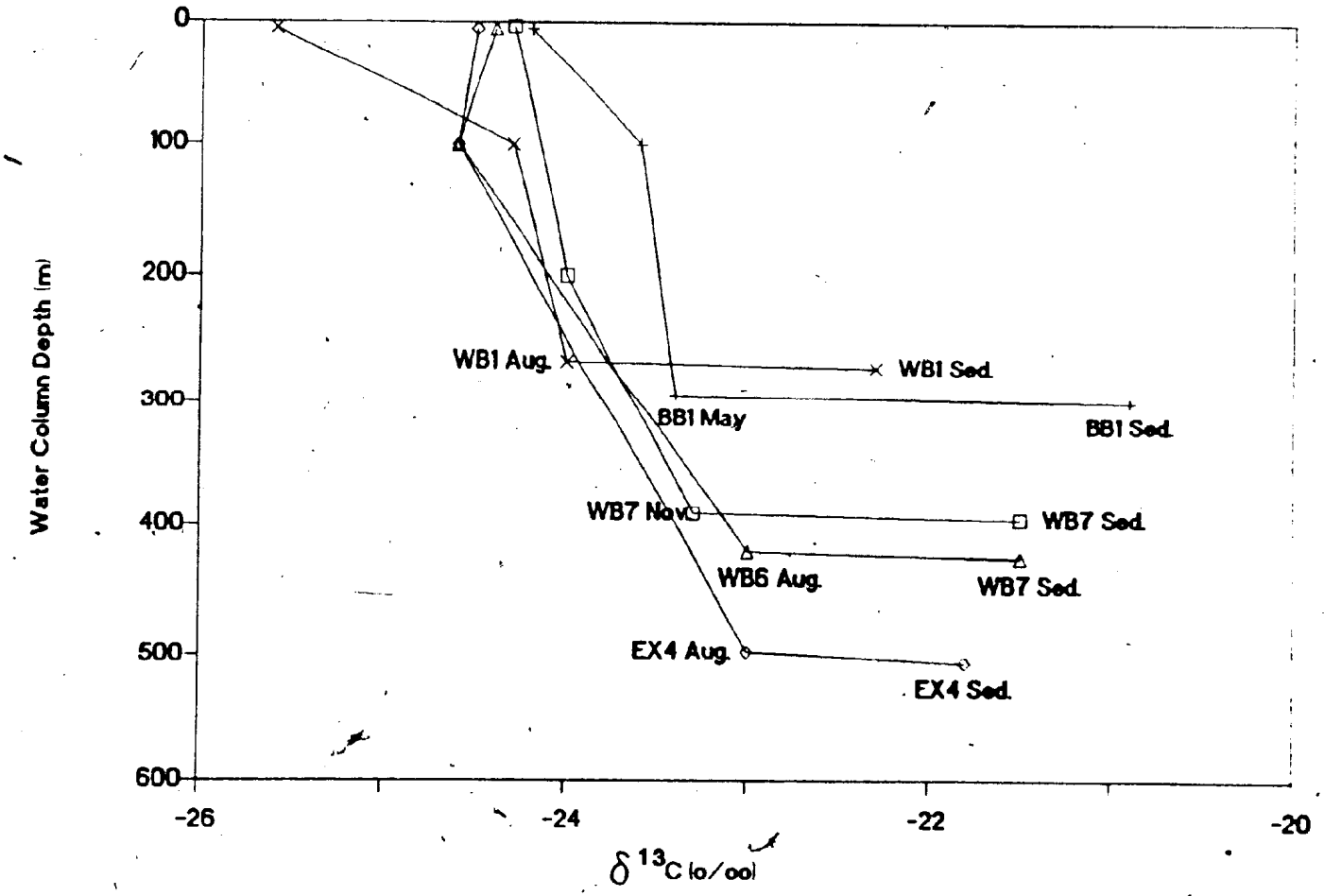

Water Column Depth (m)
0
100
200
300
400
500
600
-26
-24
-22
-20
δ 13C (o/oo)
WB1 Aug.
WB1 Sed.
BB1 May
BB1 Sed.
WB7 Nov.
WB7 Sed.
WB6 Aug.
WB7 Sed.
EX4 Aug.
EX4 Sed.

Figure 17. Carbon isotopic composition of dissolved inorganic carbon (DIC) samples with respect to depth in the water column (locations of stations given in Appendix 1).

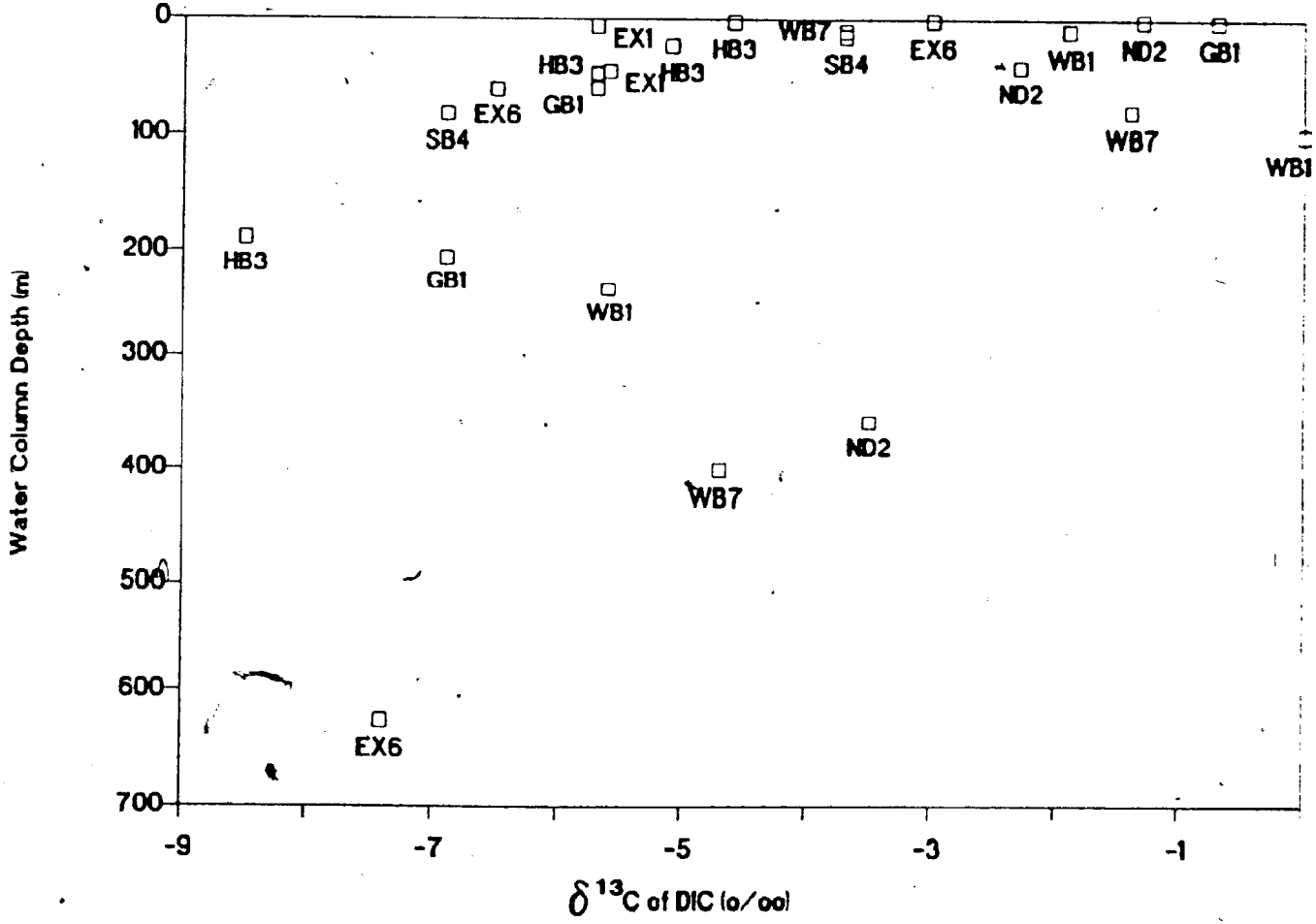

Water Column Depth (m)
0
100
200
300
400
500
600
700
-9
-7
-5
-3
-1
δ 13C of DIC (o/oo)
EX1
HB3
HB3
WB7
SB4
EX6
WB1
ND2
GB1
HB3
EX1
GB1
EX6
SB4
ND2
WB7
WB1
HB3
GB1
WB1
ND2
WB7
EX6

Figure 18. Concentration of DIC samples with respect to depth in the water column.

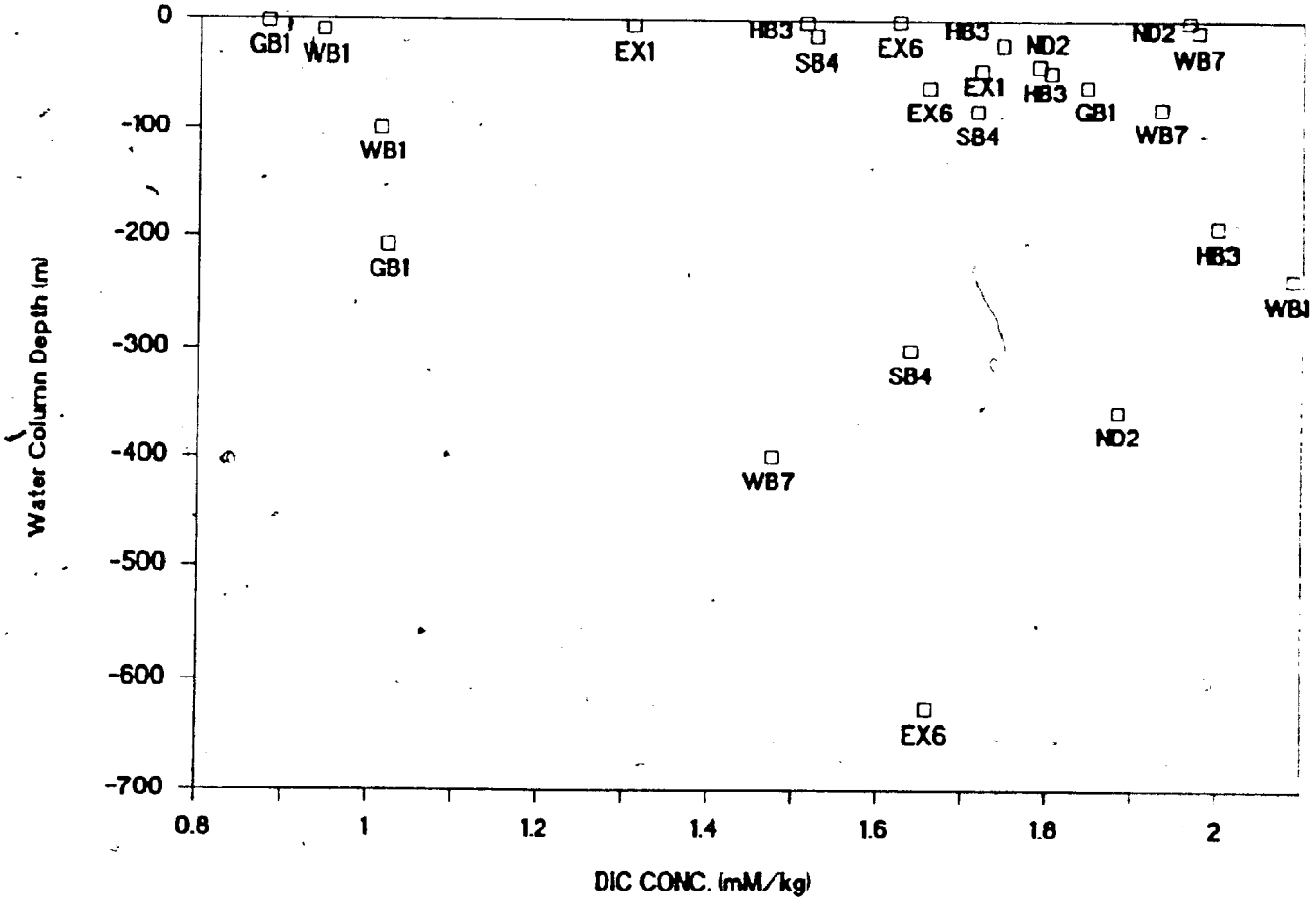

Water Column Depth (m)
0
-100
-200
-300
-400
-500
-600
-700
0.8
1
1.2
1.4
1.6
1.8
2
DIC CONC. (mM/kg)
GB1
WB1
EX1
HB3
SB4
EX6
HB3
ND2
ND2
WB7
EX1
HB3
EX6
GB1
SB4
WB7
WB1
GB1
HB3
WB1
SB4
ND2
WB7
EX6

Figure 19. Frequency of $\delta^{15}N$ occurrences for surface water seston and surficial sediment samples.

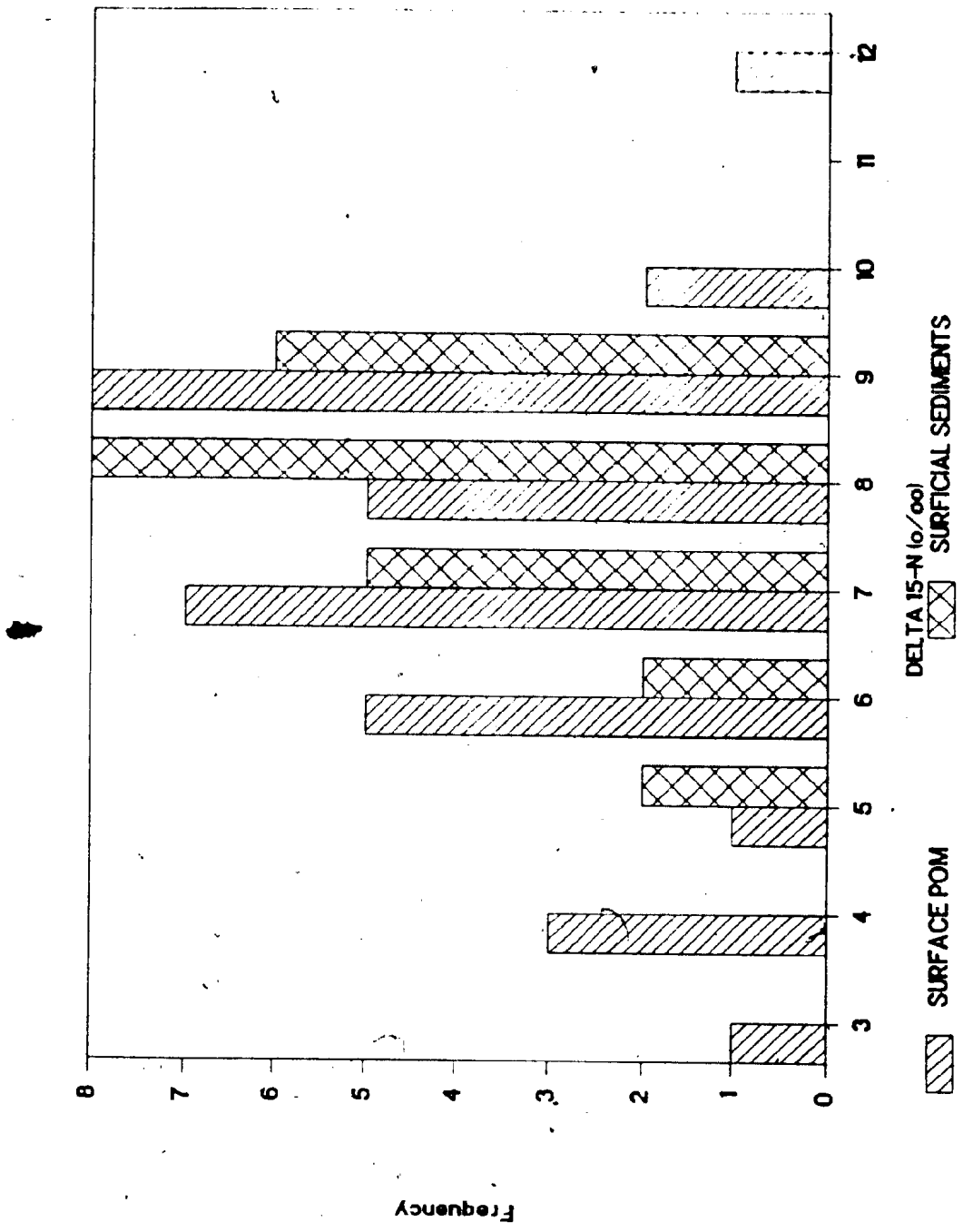

Frequency
0
1
2
3
4
5
6
7
8
3
4
5
6
7
8
9
10
11
12
DELTA 15-N (o/oo)
SURFICIAL SEDIMENTS
SURFACE POM

Figure 20. Frequency of $\delta^{13}C$ occurrences for surface water seston and surficial sediment samples.

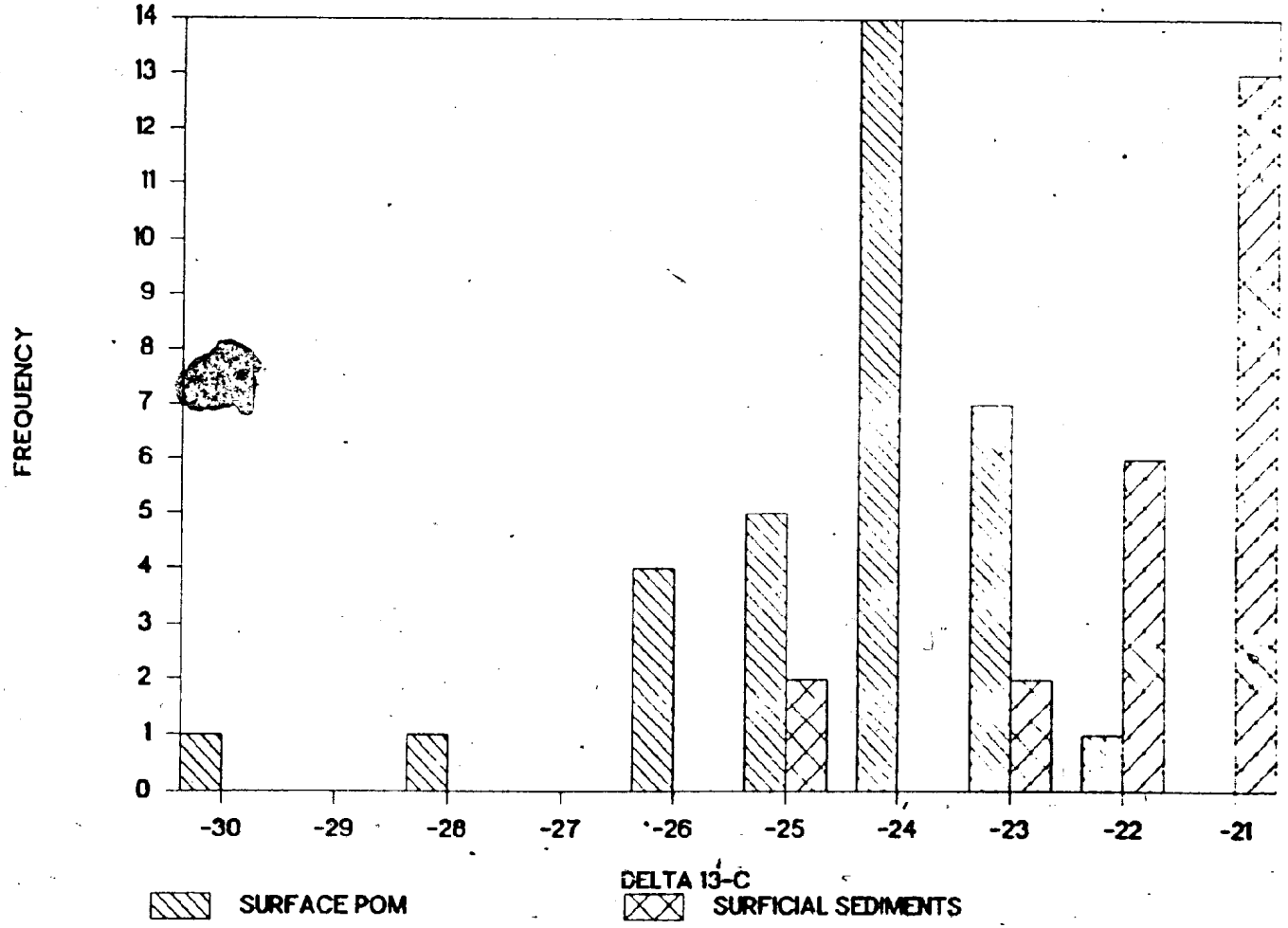

FREQUENCY
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-30
-29
-28
-27
-26
-25
-24
-23
-22
-21
DELTA 13-C
SURFACE POM
SURFICIAL SEDIMENTS

Figure 21. Nearshore to offshore transects showing the $\delta^{15}N$ of surficial sediments from Exploits and Conception Bays.

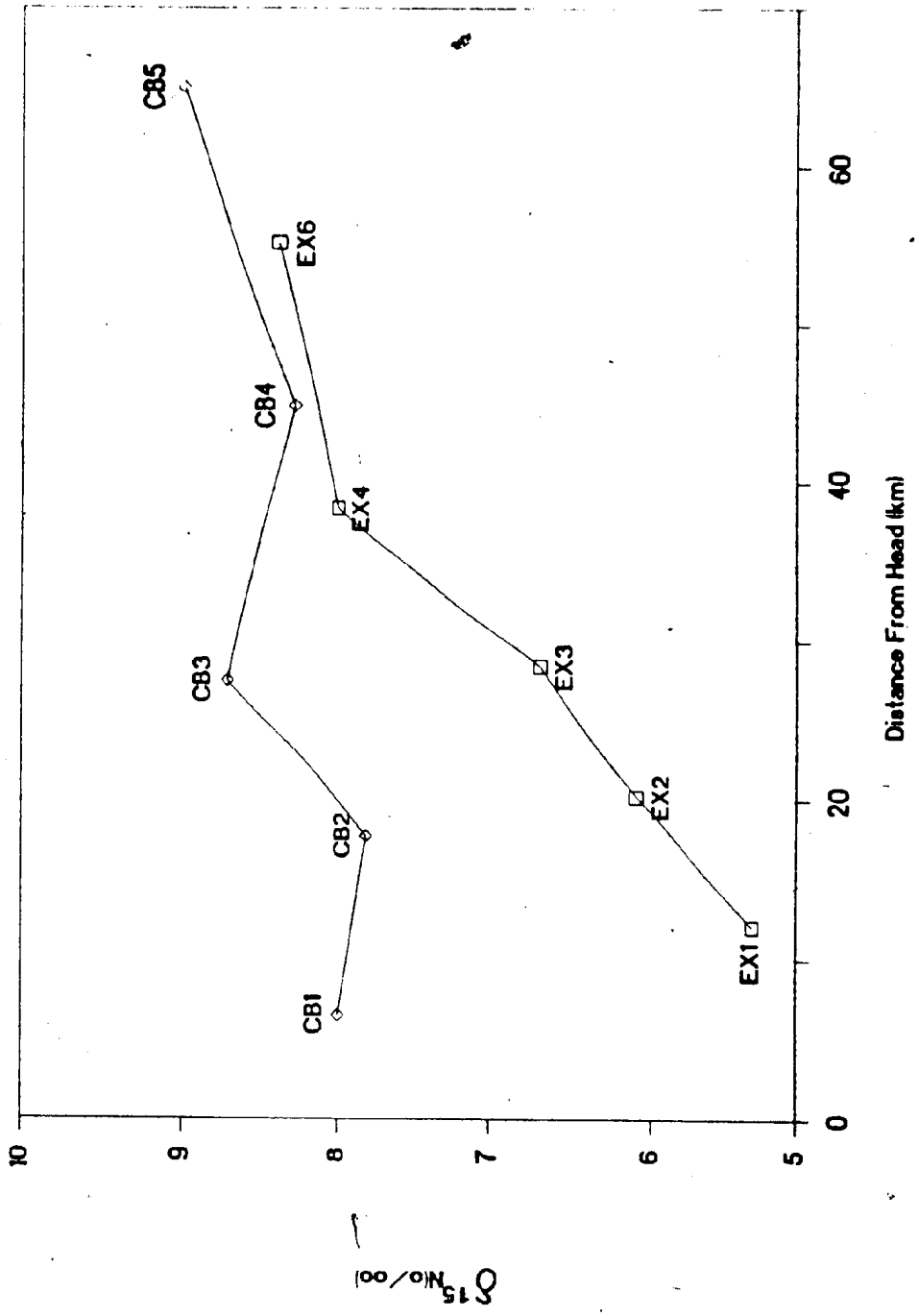

CB5
EX6
CB4
EX4
CB3
EX3
CB2
EX2
CB1
EX1
10
9
8
7
6
5
0
20
40
60
Distance From Head (km)
δ15N(o/oo)

Figure 22. Nearshore to offshore transects showing the $\delta^{13}C$ of surficial sediments from Exploits and Conception Bays.

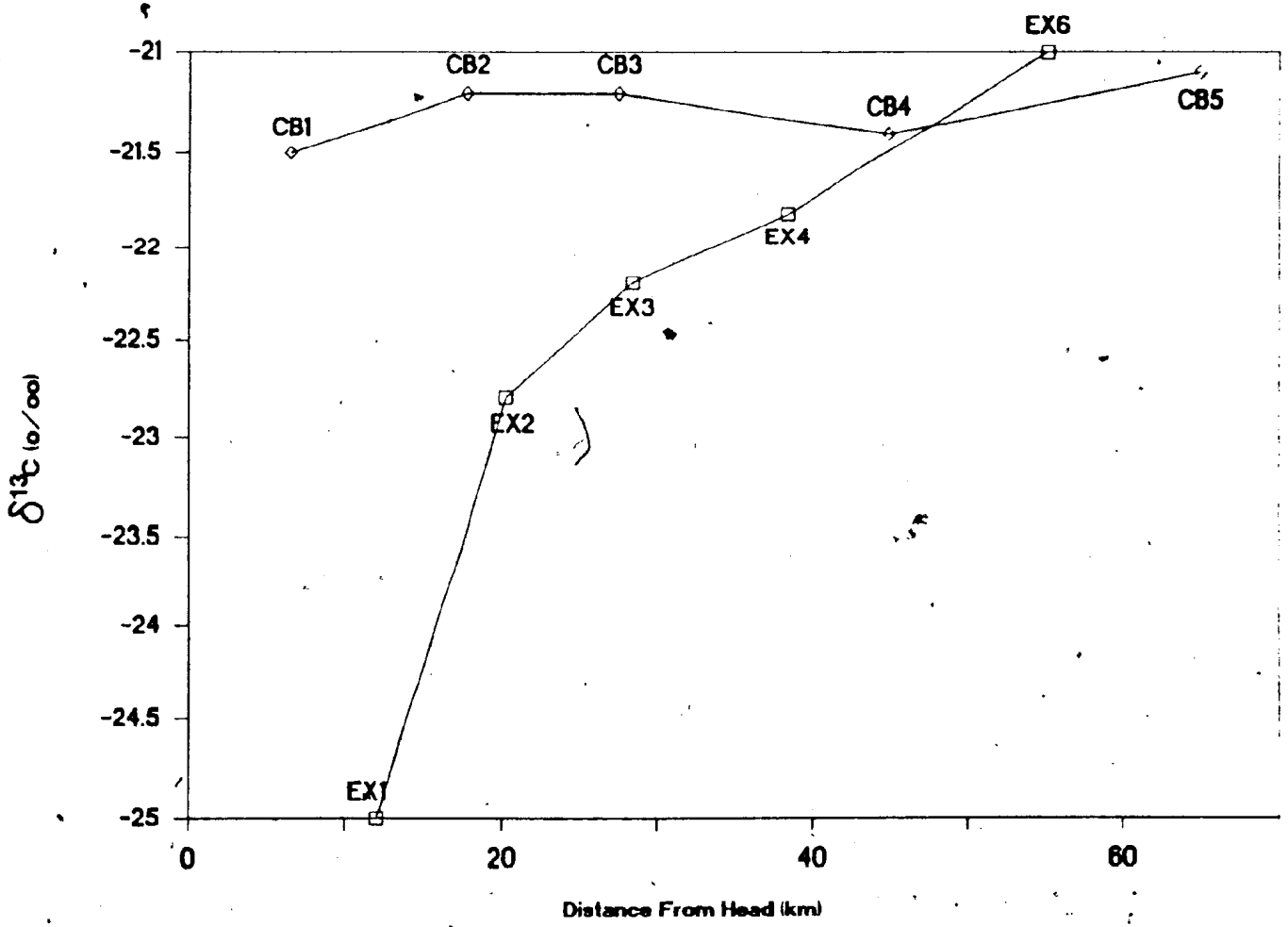

EX6
CB2
CB3
CB4
CB5
CB1
EX4
EX3
EX2
EX1
-21
-21.5
-22
-22.5
-23
-23.5
-24
-24.5
-25
0
20
40
60
δ13C (o/oo)
Distance From Head (km)

Figure 23. Sediment descriptions and average isotopic compositions of the units, subunits and zones in core SB3.

Depth (cm)	Unit	Description	average $\delta^{13}N$ (°/oo)	average $\delta^{13}C$ (°/oo)
0	1	Dark olive gray with black mottling low carbonate	7.7	-22.6
55				
	2a	Olive gray, slightly mottled black moderate carbonate content	7.4	-24.1
163				
	2b	Grayish brown mud very high carbonate content	6.1	-24.9
177				
	2c-1	Olive gray, slightly mottled black moderate carbonate content	6.0	-23.7
195				
	2c-2	Reddish gray moderate carbonate content	7.2	-22.2
256				
	2c-3	Olive gray to brownish gray mud moderate carbonate content	7.9	-22.2
325				
	2c-4	Similar to 2c-3	6.4	-23.1
395				
	3	Reddish gray mud with olive gray diatom rich laminations low carbonate content	4.6	-24.2
443				
	4	Firm light red mud low carbonate content	4.7	-23.6
505				
	5	Poorly sorted, red and sandy mud low carbonate content	4.3	-25.3
526				

Figure 24. Grain size data for core SB3

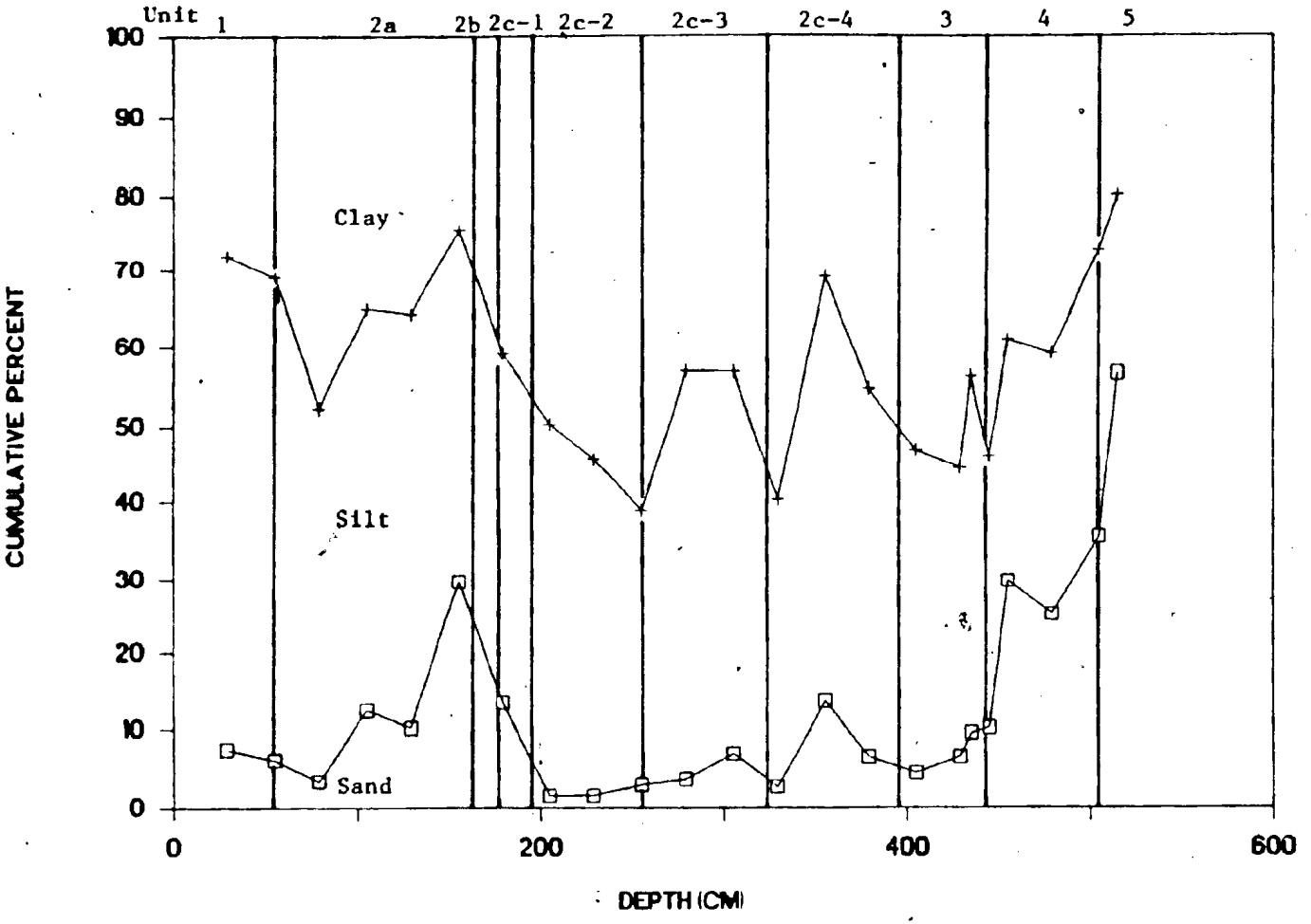

Unit
1
2a
2b
2c-1
2c-2
2c-3
2c-4
3
4
5
100
90
80
70
60
50
40
30
20
10
0
Clay
Silt
Sand
CUMULATIVE PERCENT
0
200
400
600
DEPTH (CM)

Figure 25. Carbon and nitrogen isotope data for core SB3.

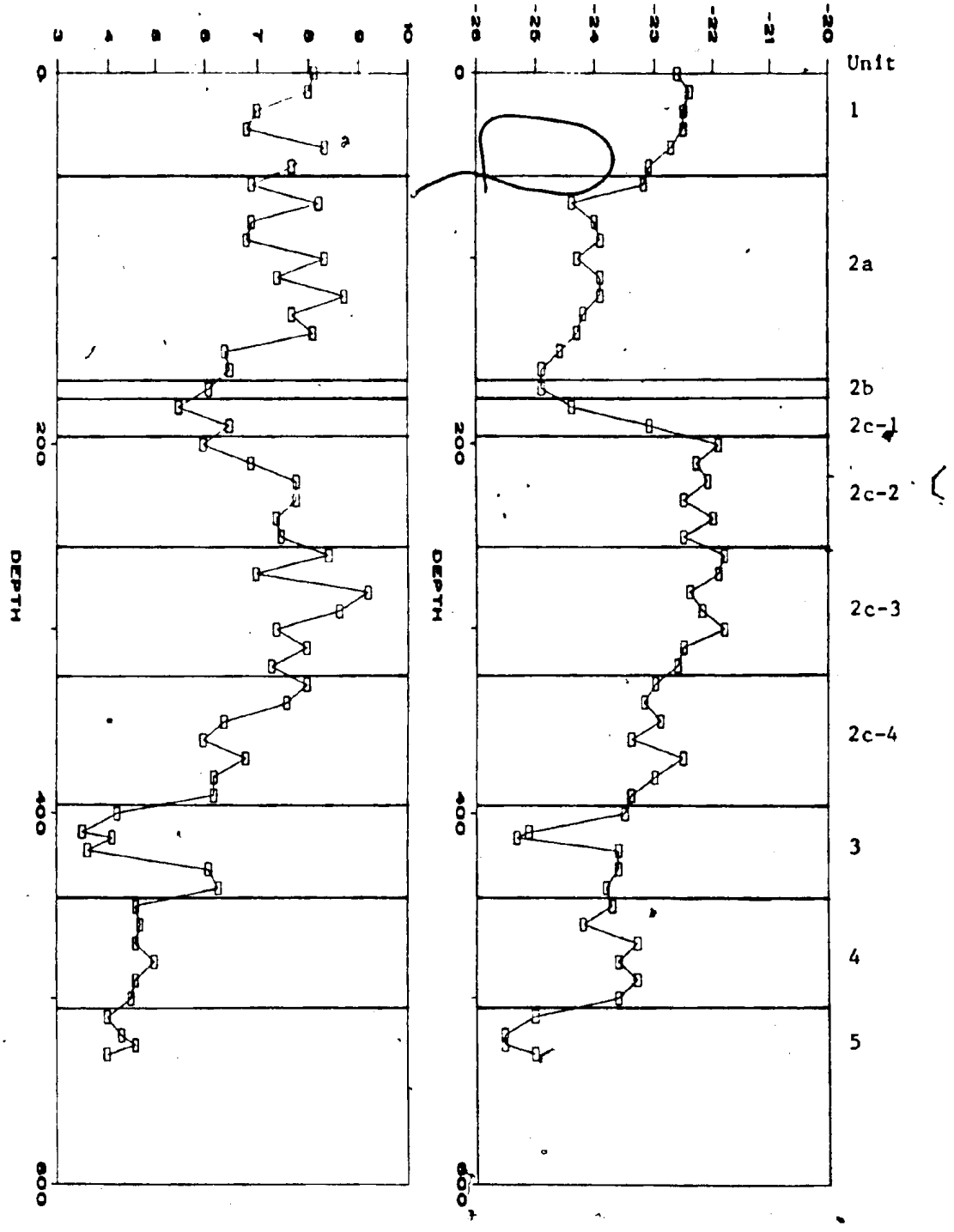

δ15N‰
δ13C‰
DEPTH
DEPTH
Unit
1
2a
2b
2c-1
2c-2
2c-3
2c-4
3
4
5

Figure 26. Carbon and nitrogen abundance data for core SB3.

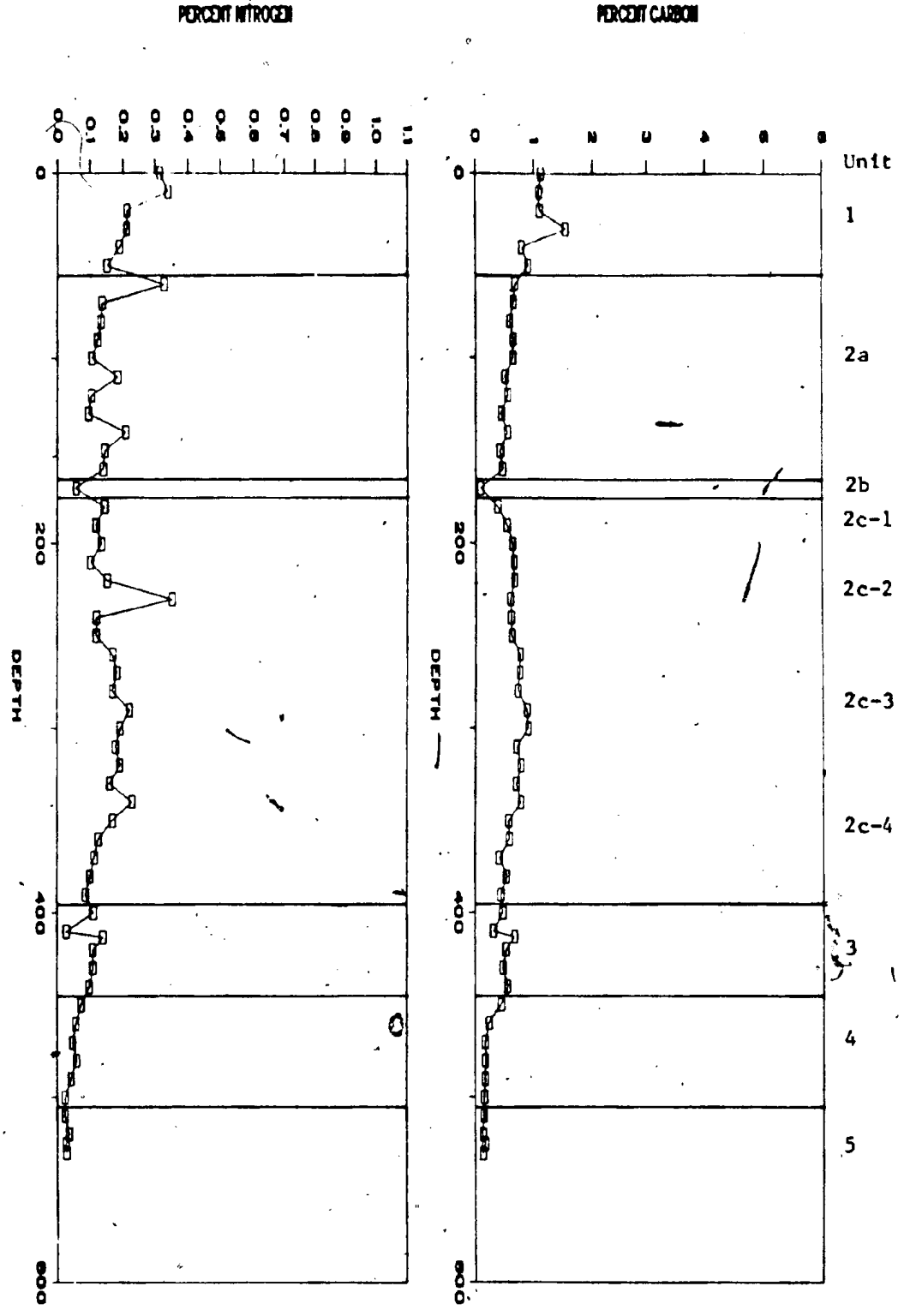

PERCENT NITROGEN
PERCENT CARBON
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
0
1
2
3
4
5
6
7
8
Unit
1
2a
2b
2c-1
2c-2
2c-3
2c-4
3
4
5
DEPTH
200
400
600

Figure 27. Carbon to nitrogen ratio data for core SB3.

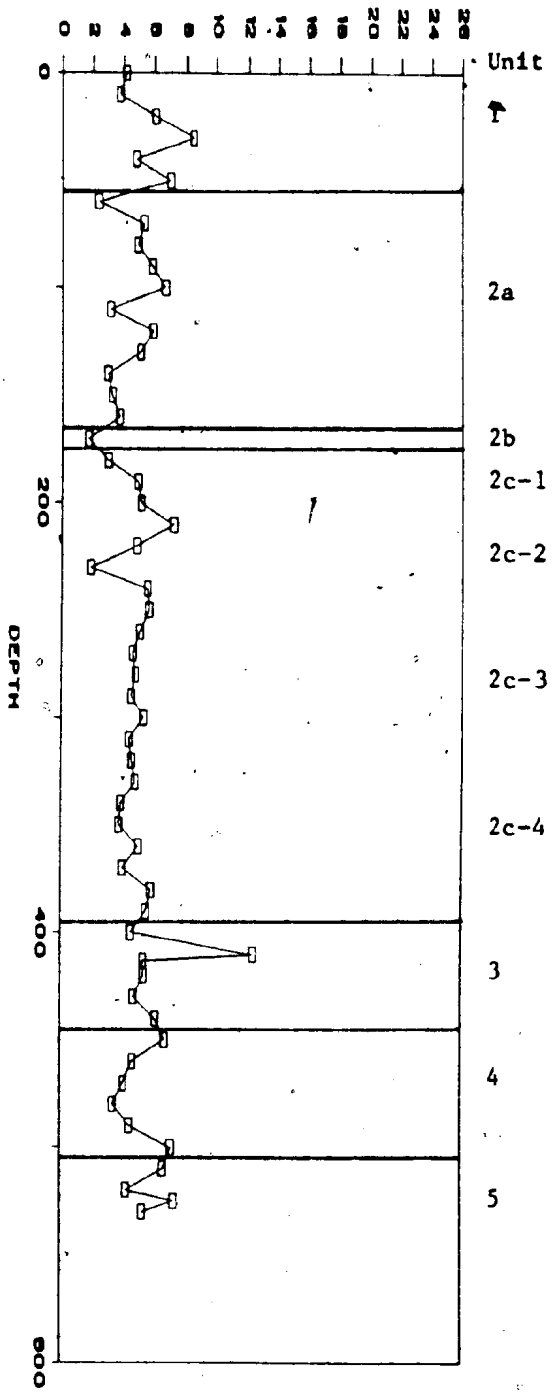

C/N
Unit
1
2a
2b
2c-1
2c-2
2c-3
2c-4
3
4
5
DEPTH
0
200
400
600

Figure 28. Carbon and nitrogen isotope data for core WB1.

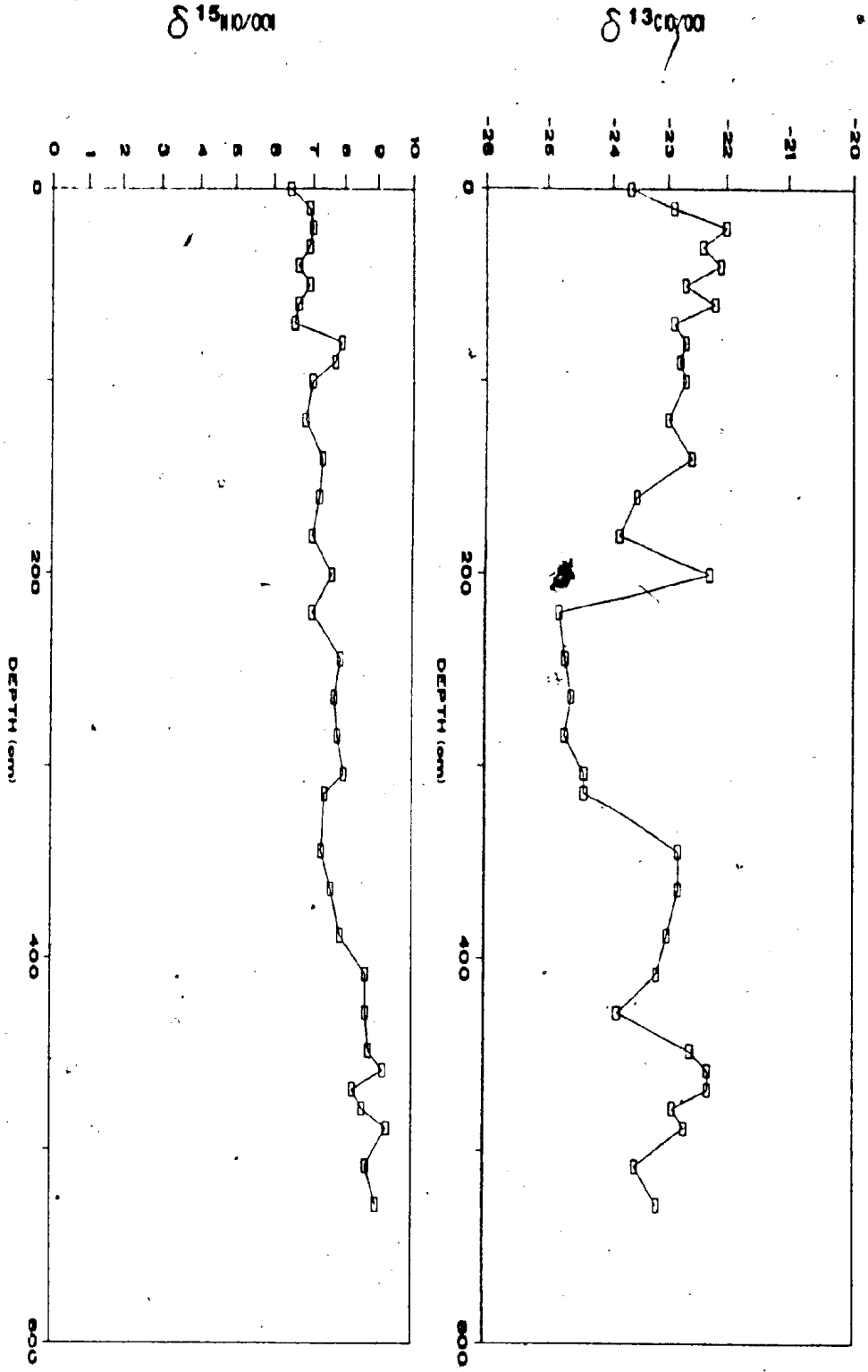
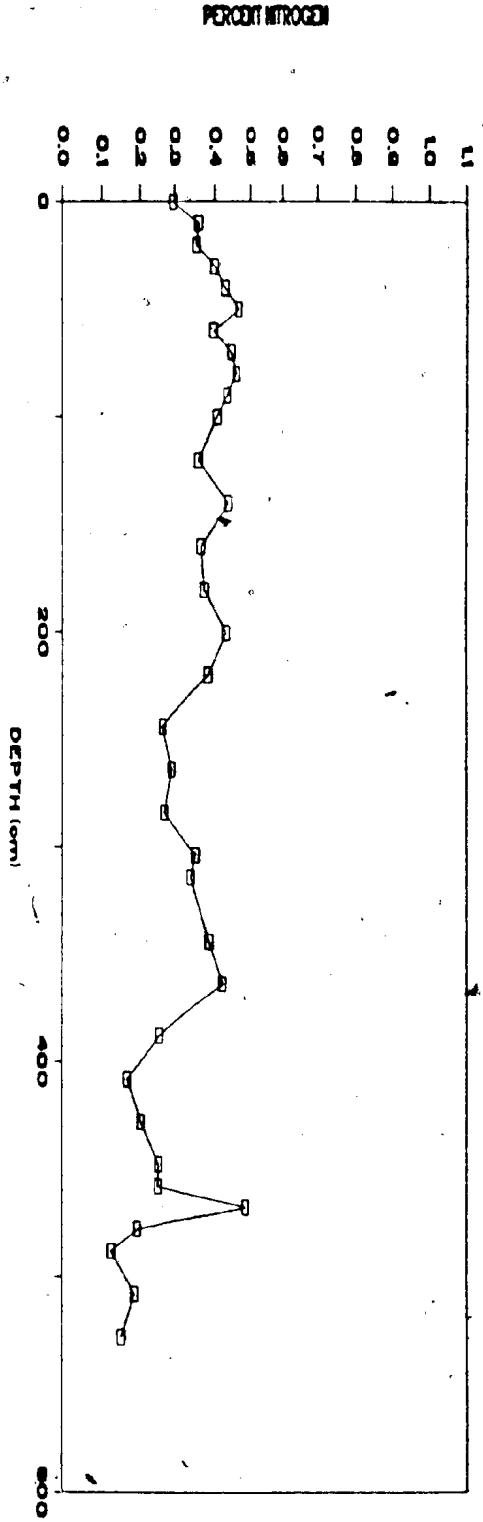

δ 15N o/oo
δ 13C o/oo
DEPTH (cm)
0
200
400
600
-20
-21
-22
-23
-24
-25
-26

Figure 29. Carbon and nitrogen abundance data for core WB1.


PERCENT NITROGEN
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
0
200
400
600
DEPTH (cm)

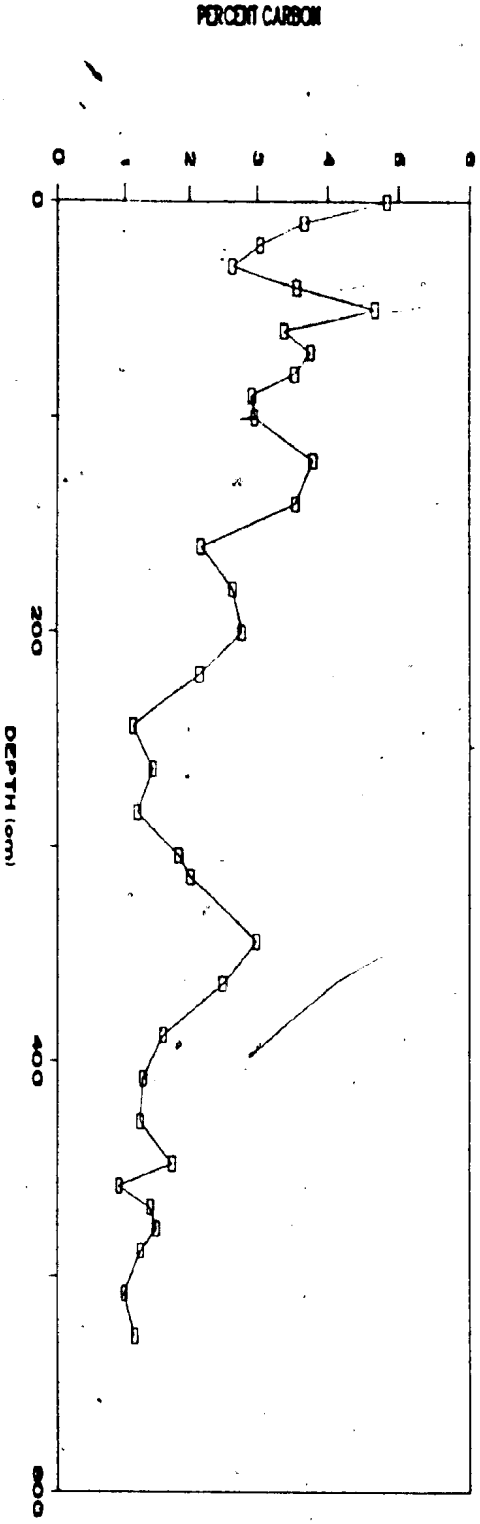
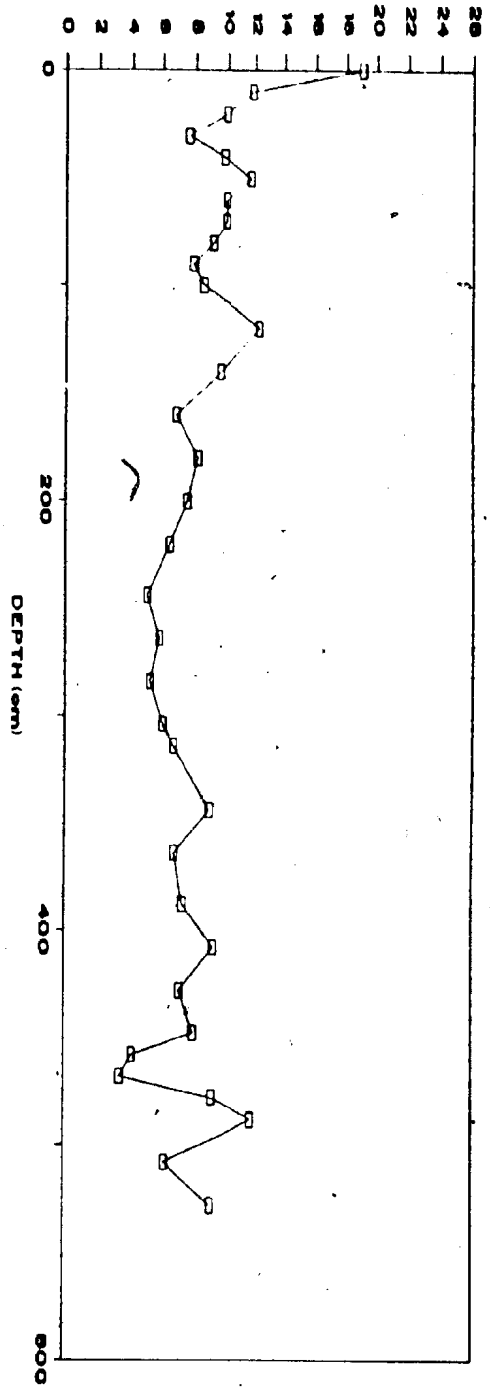

PERCENT CARBON
0
1
2
3
4
5
0
200
400
600
DEPTH (cm)

Figure 30. Carbon to nitrogen ratio data for core WB1.

CM



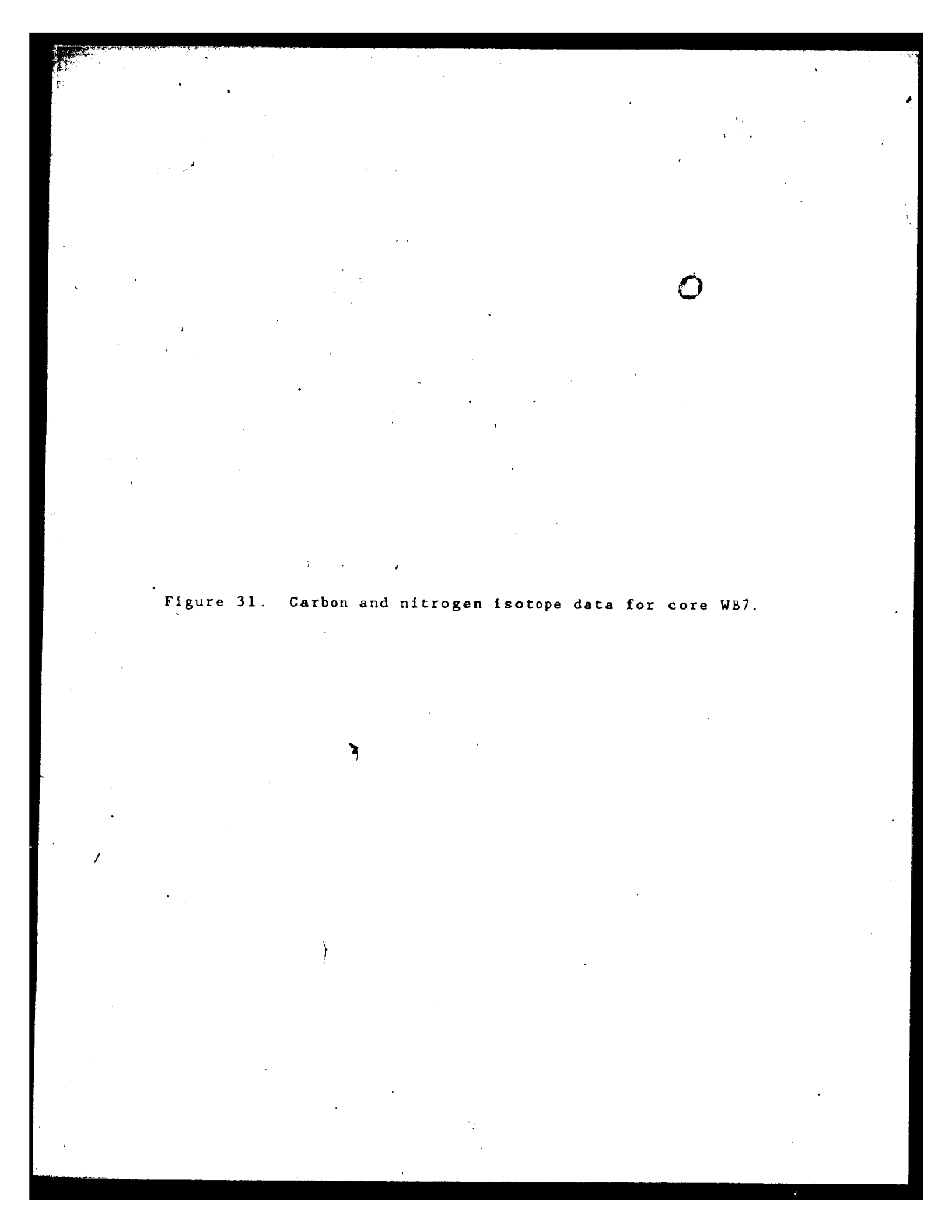


Figure 31. Carbon and nitrogen isotope data for core WB7.

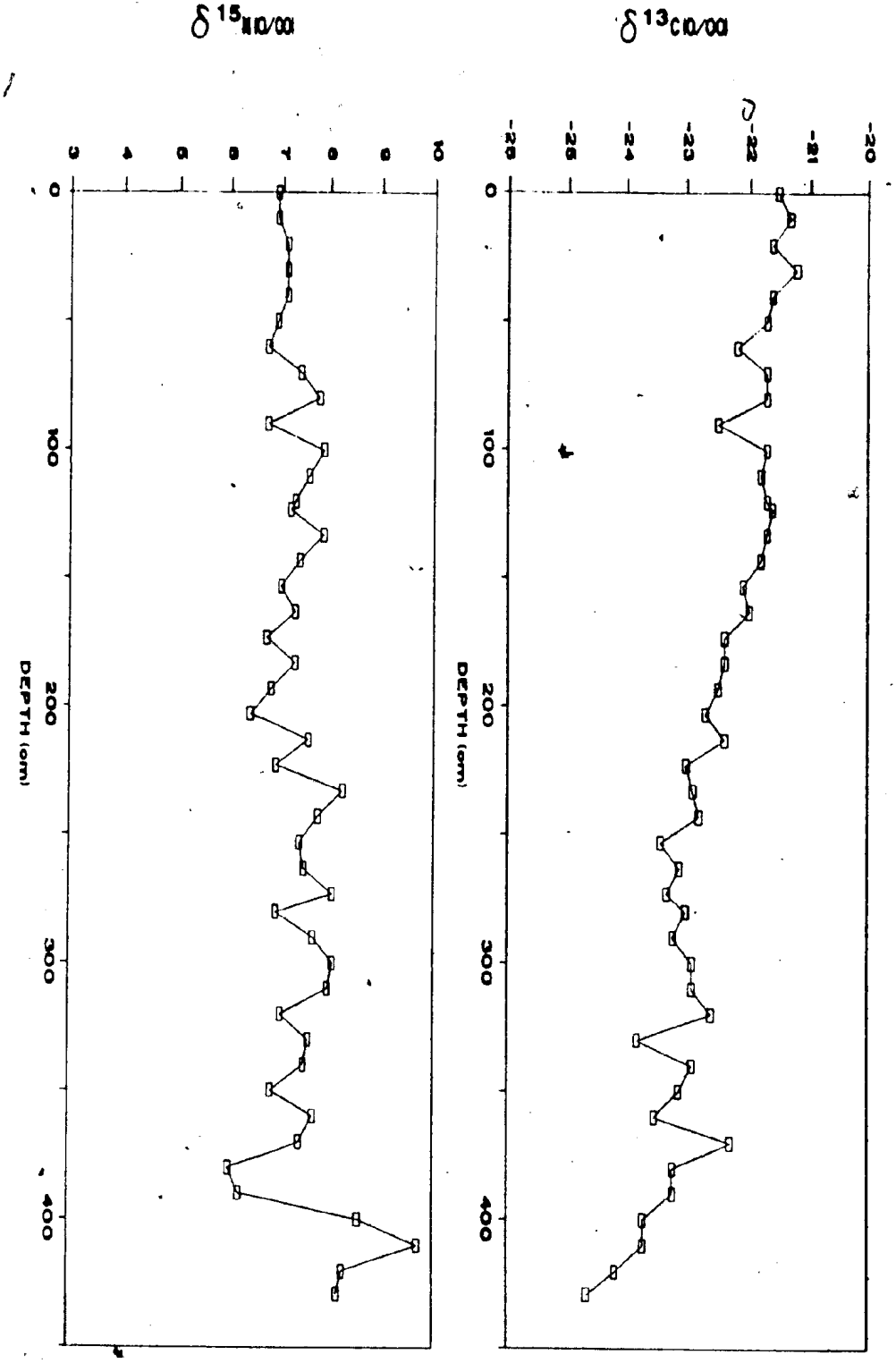

δ 15N‰
δ 13C‰
DEPTH (cm)
0
100
200
300
400
-20
-21
-22
-23
-24
-25
-26

Figure 32. Carbon and nitrogen abundance data for core WB7.

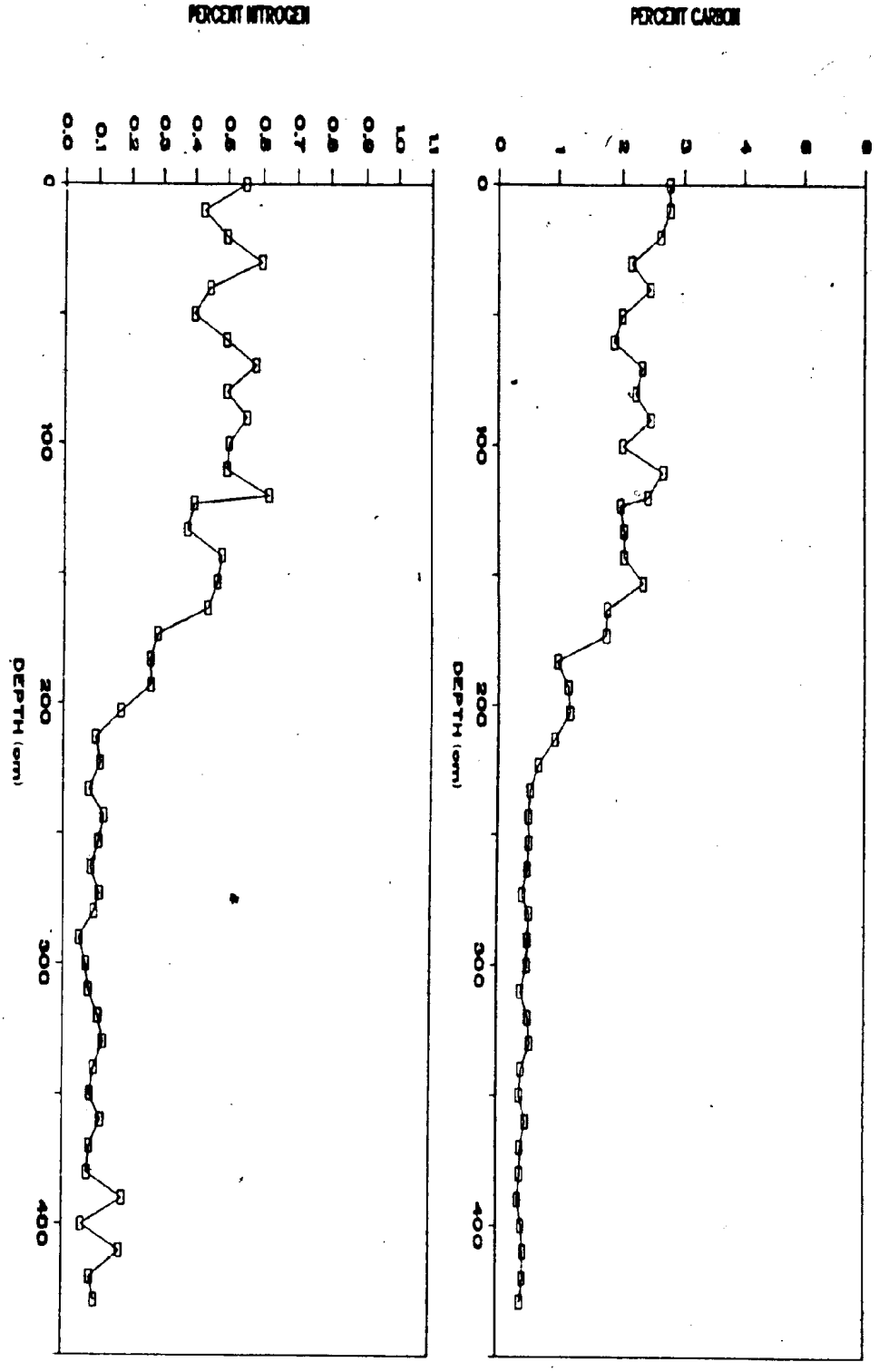
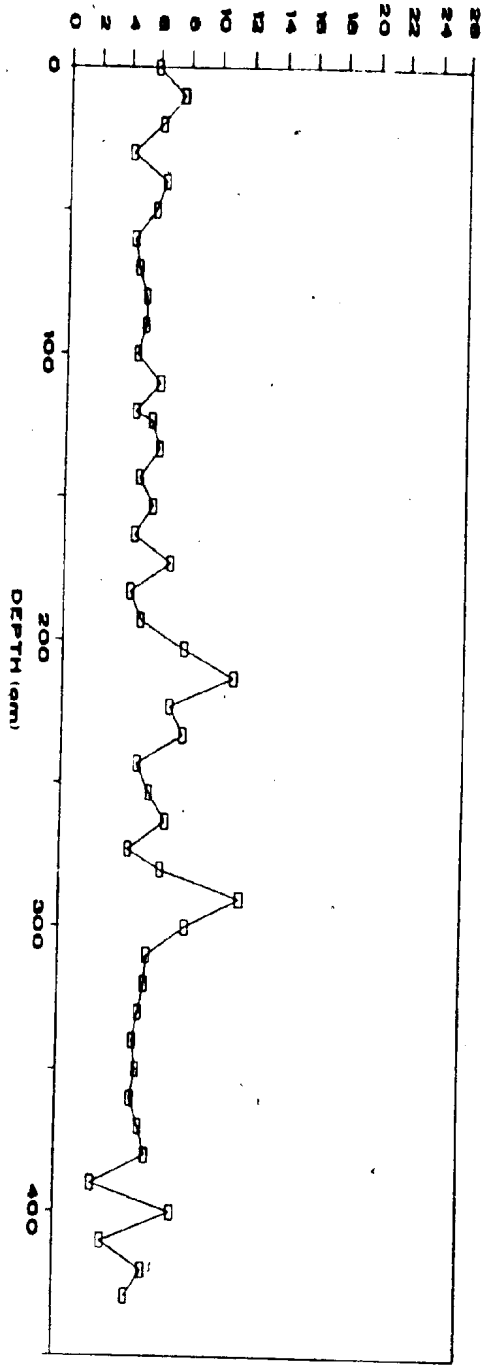

PERCENT NITROGEN
PERCENT CARBON
DEPTH (cm)
0
100
200
300
400

Figure 33. Carbon to nitrogen ratio data for core WB7.

C/N



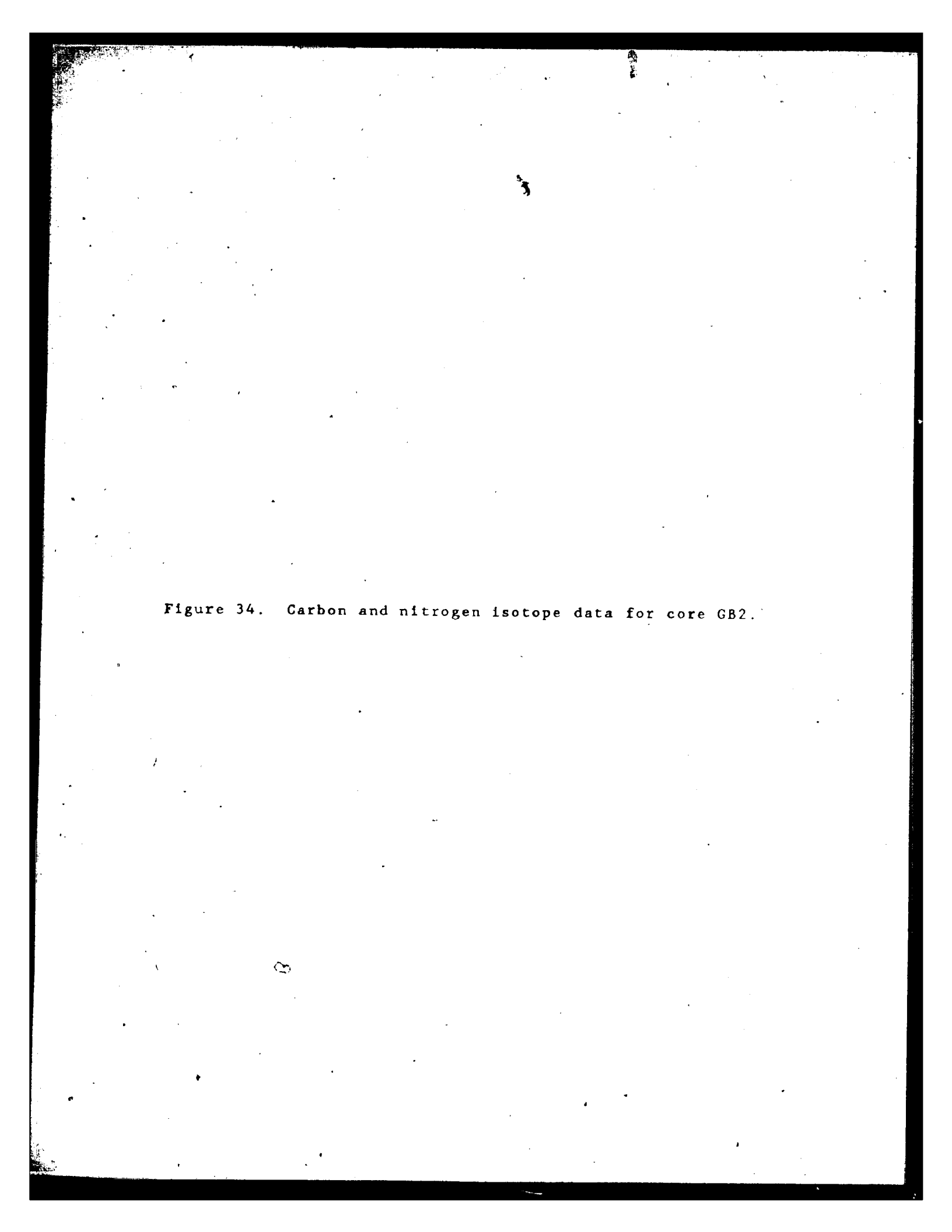


Figure 34. Carbon and nitrogen isotope data for core GB2.

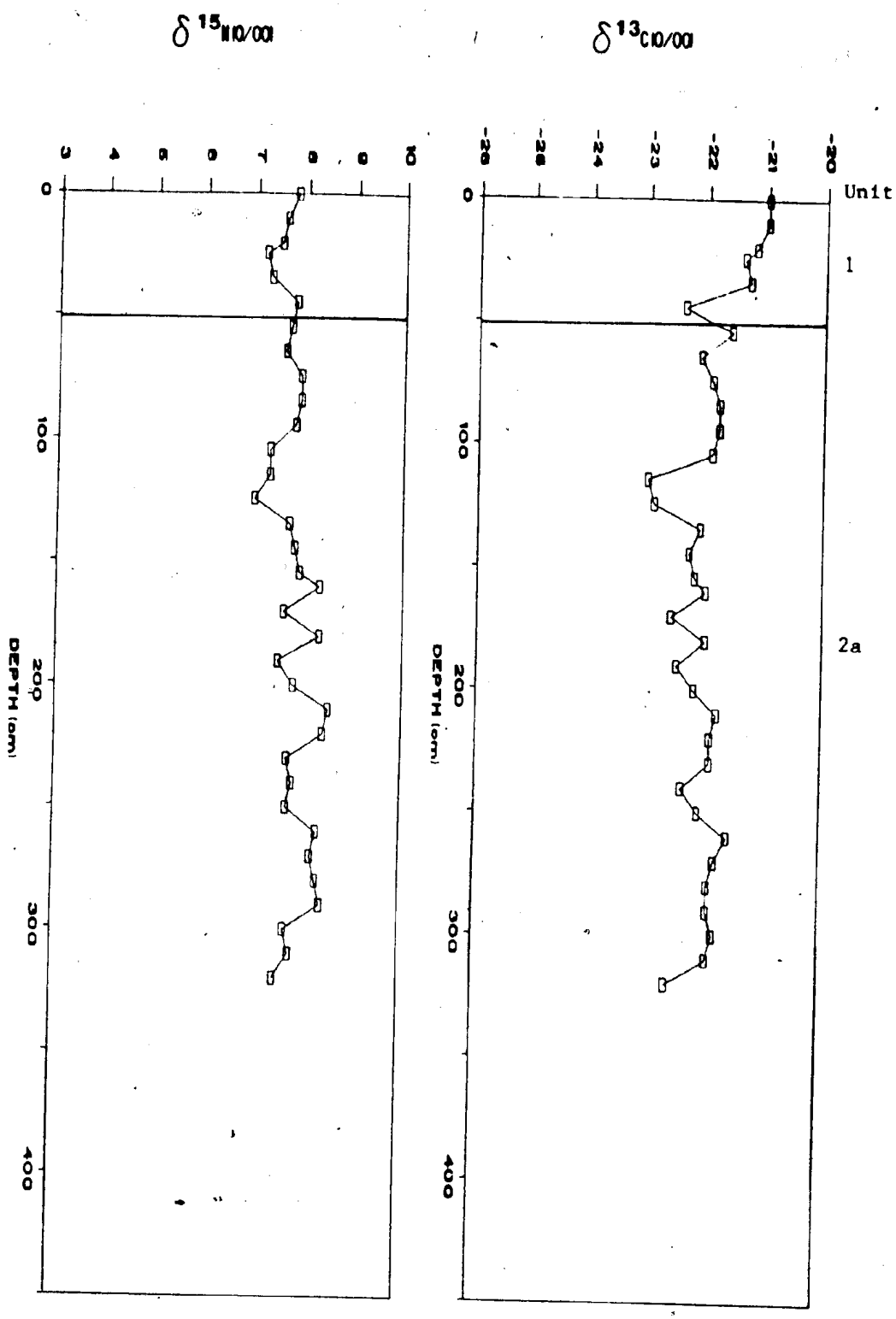

δ 15N‰
δ 13C‰
DEPTH (cm)
0
100
200
300
400
Unit
1
2a

Figure 35. Carbon and nitrogen abundance data for core GB2.

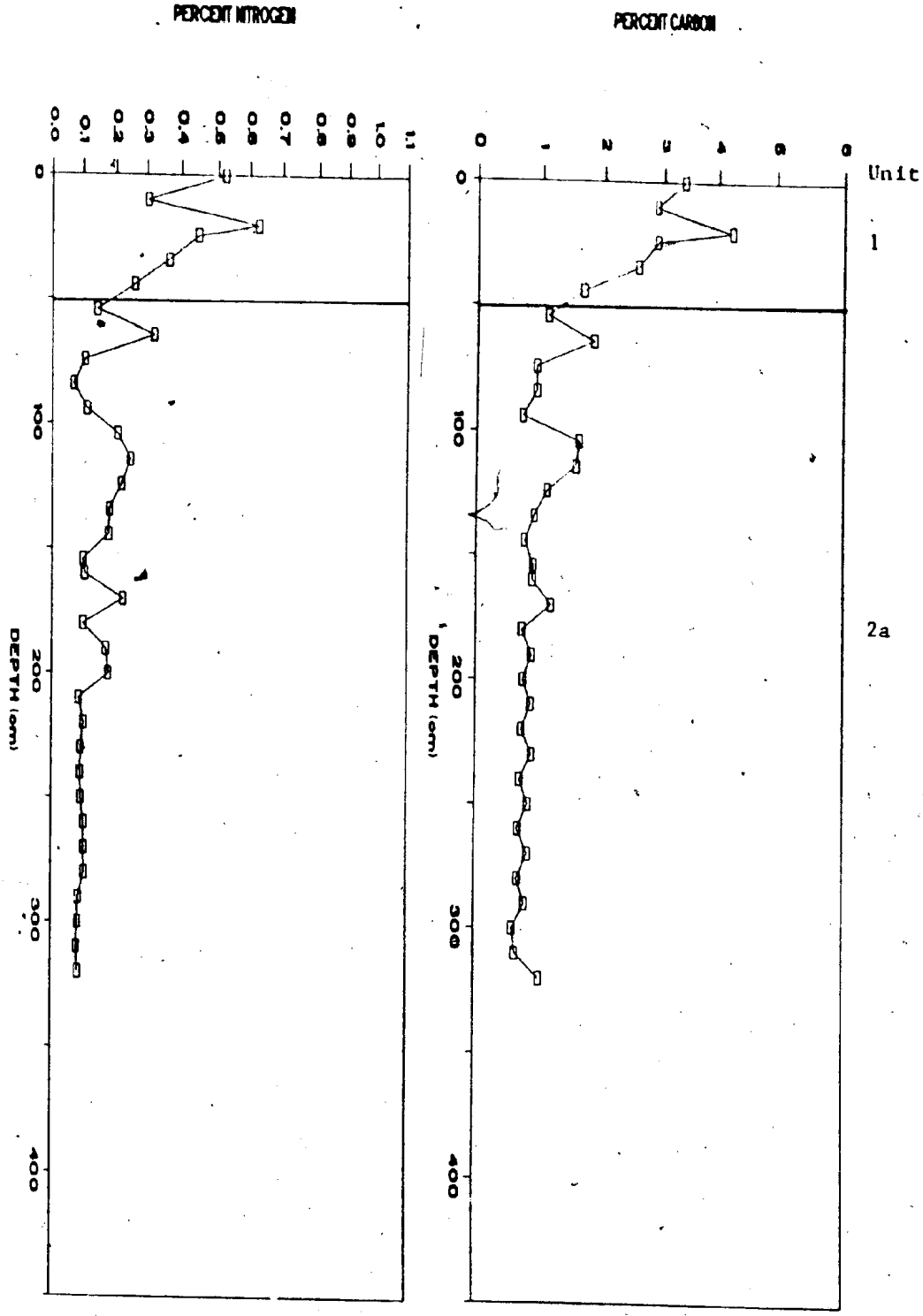

PERCENT NITROGEN
PERCENT CARBON
DEPTH (cm)
Unit
1
2a

Figure 36. Carbon to nitrogen ratio data for core GB2.

C/N

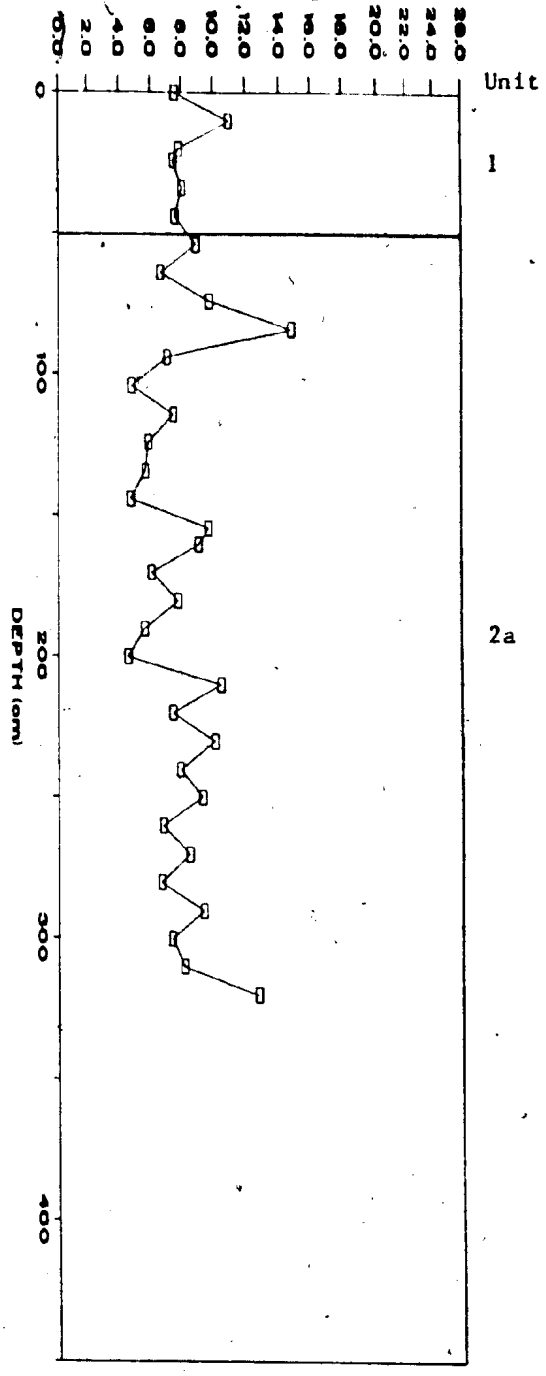

0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
0
100
200
300
400
DEPTH (cm)
Unit
1
2a

Figure 37. Carbon and nitrogen isotope data for core HB2.

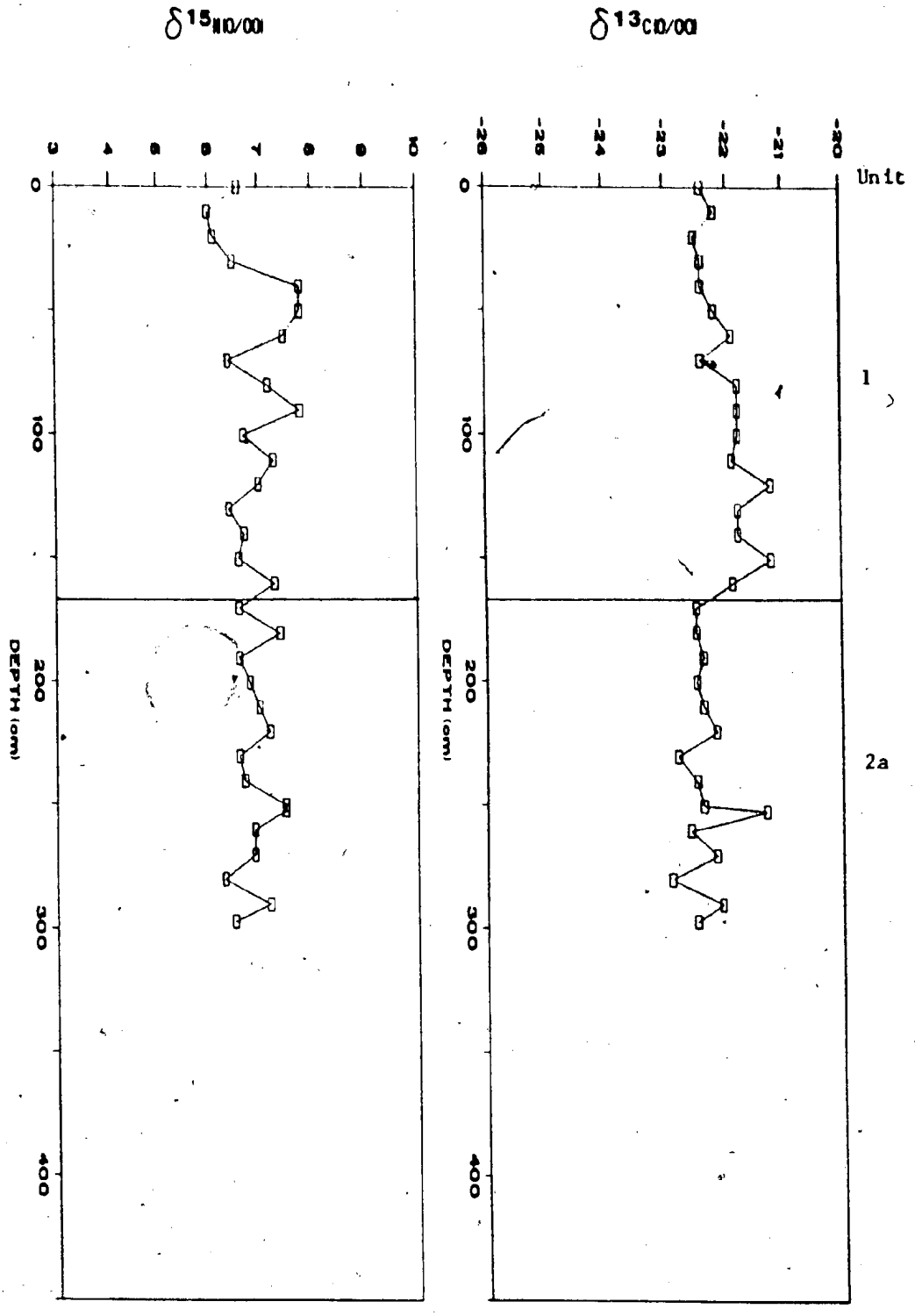

δ15N‰
δ13C‰
Unit
1
2a
DEPTH (cm)
0
100
200
300
400

Figure 38. Carbon and nitrogen abundance data for core HB2.

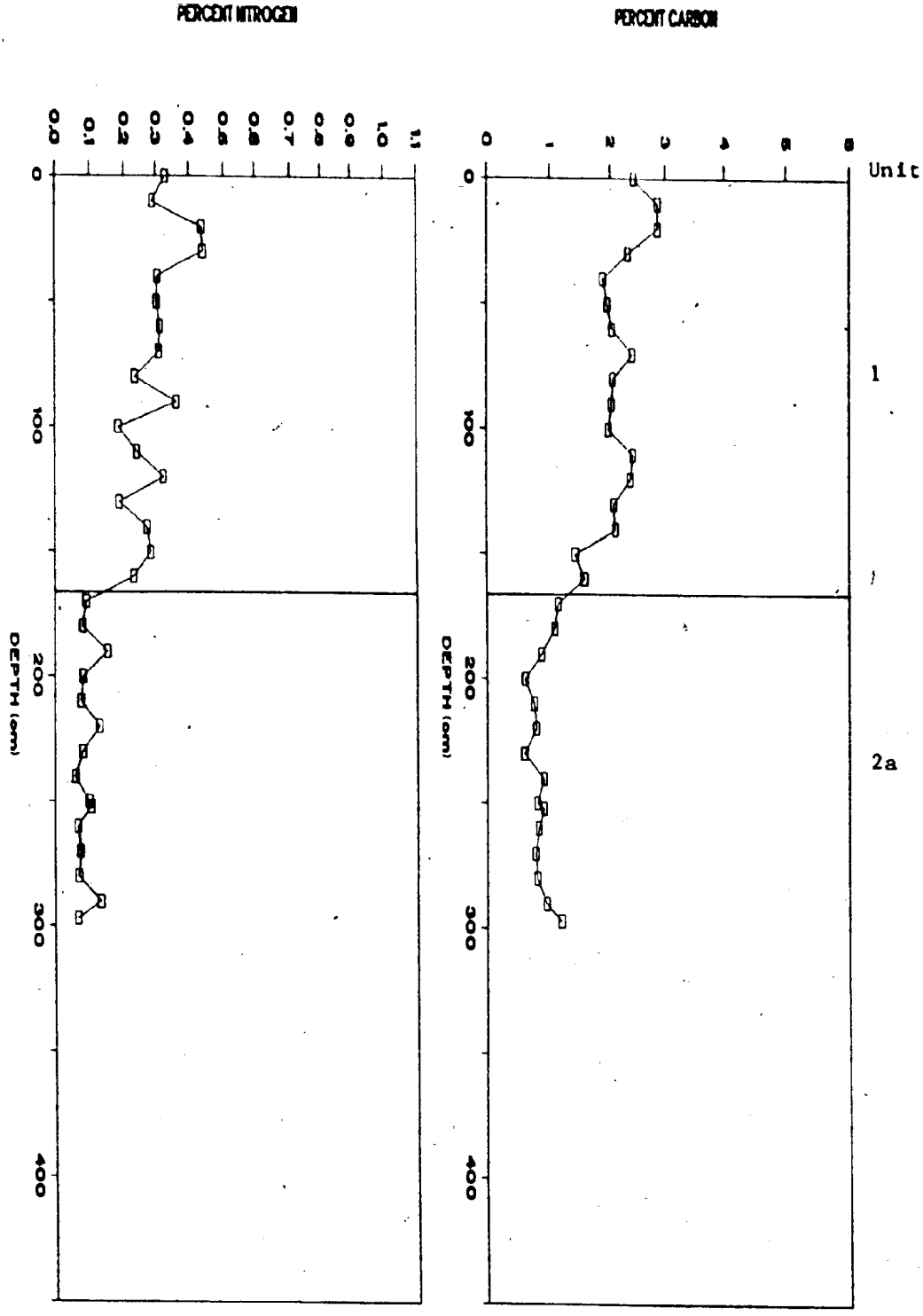

PERCENT NITROGEN
PERCENT CARBON
DEPTH (cm)
Unit
1
2a

Figure 39. Carbon to nitrogen ratio data for core HB2.

C/1

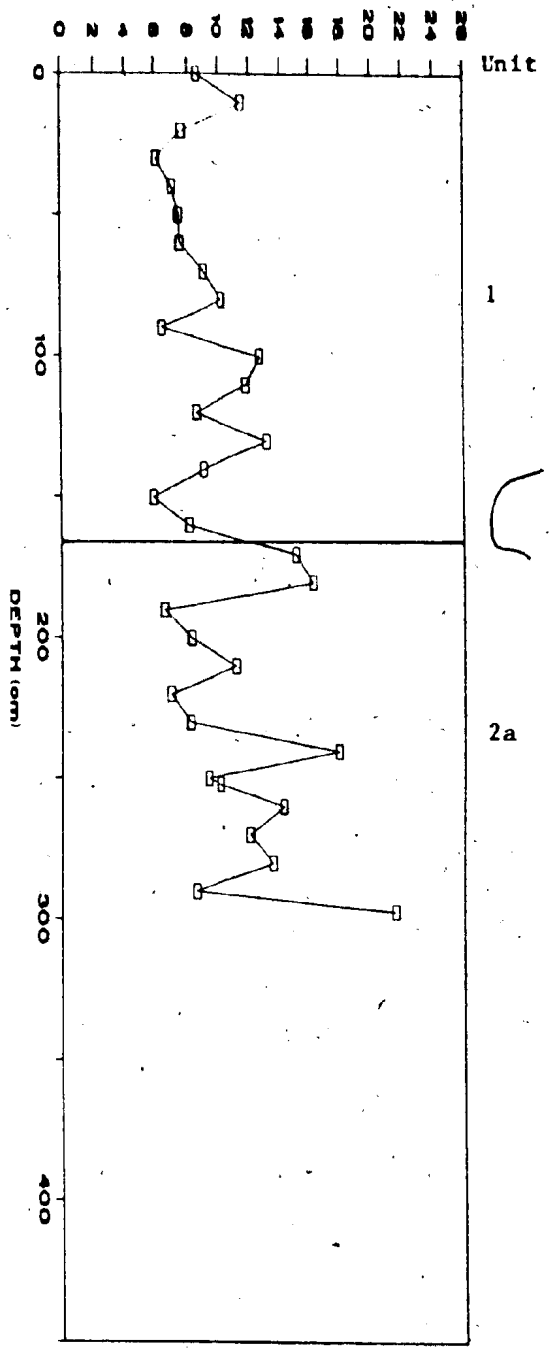


Figure 40. Carbon and nitrogen isotope data for core EX6.

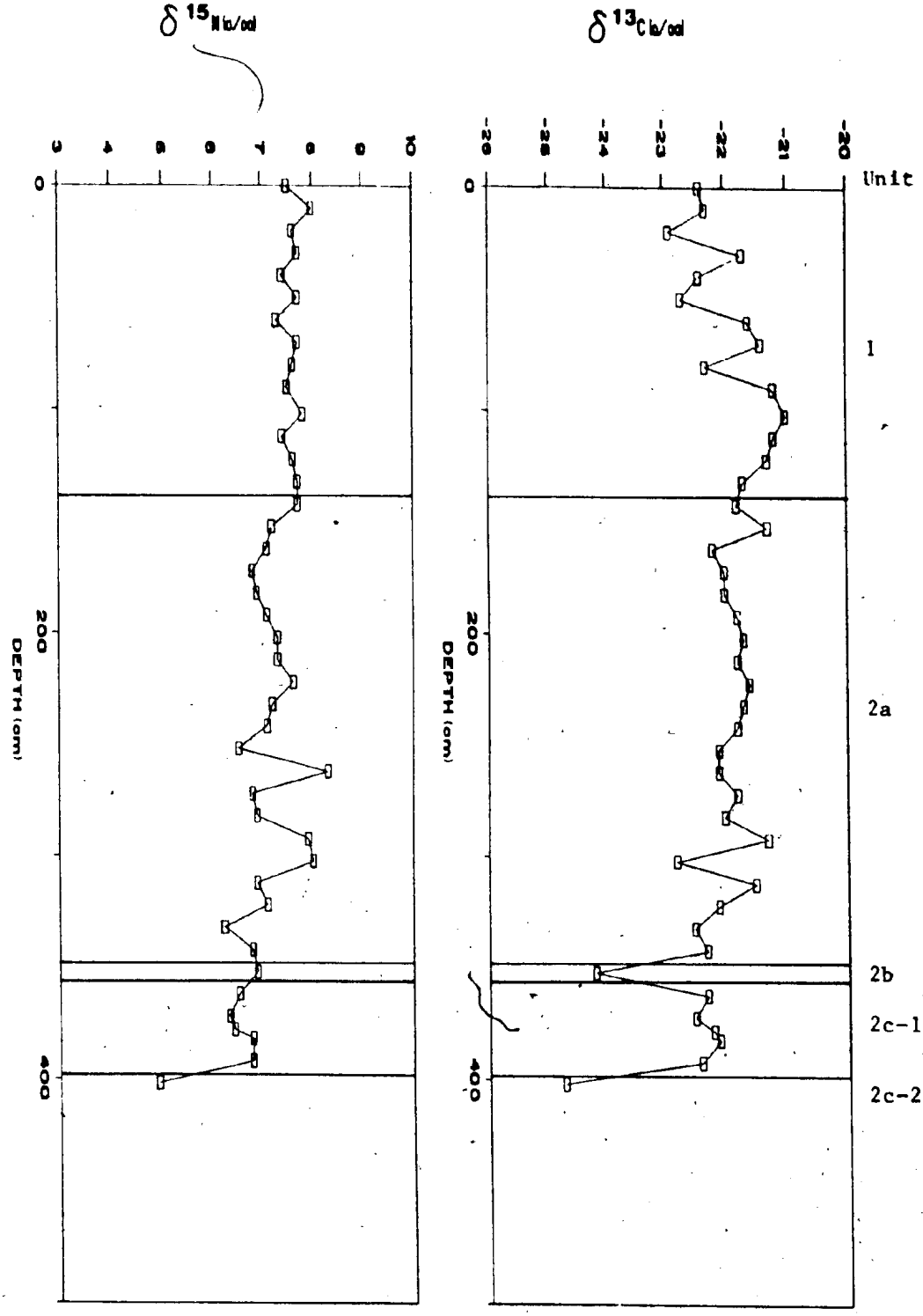

δ 15N (‰)
δ 13C (‰)
-20
-21
-22
-23
-24
-25
-26
0
200
400
DEPTH (cm)
Unit
1
2a
2b
2c-1
2c-2

Figure 41. Carbon and nitrogen abundance data for core EX6.

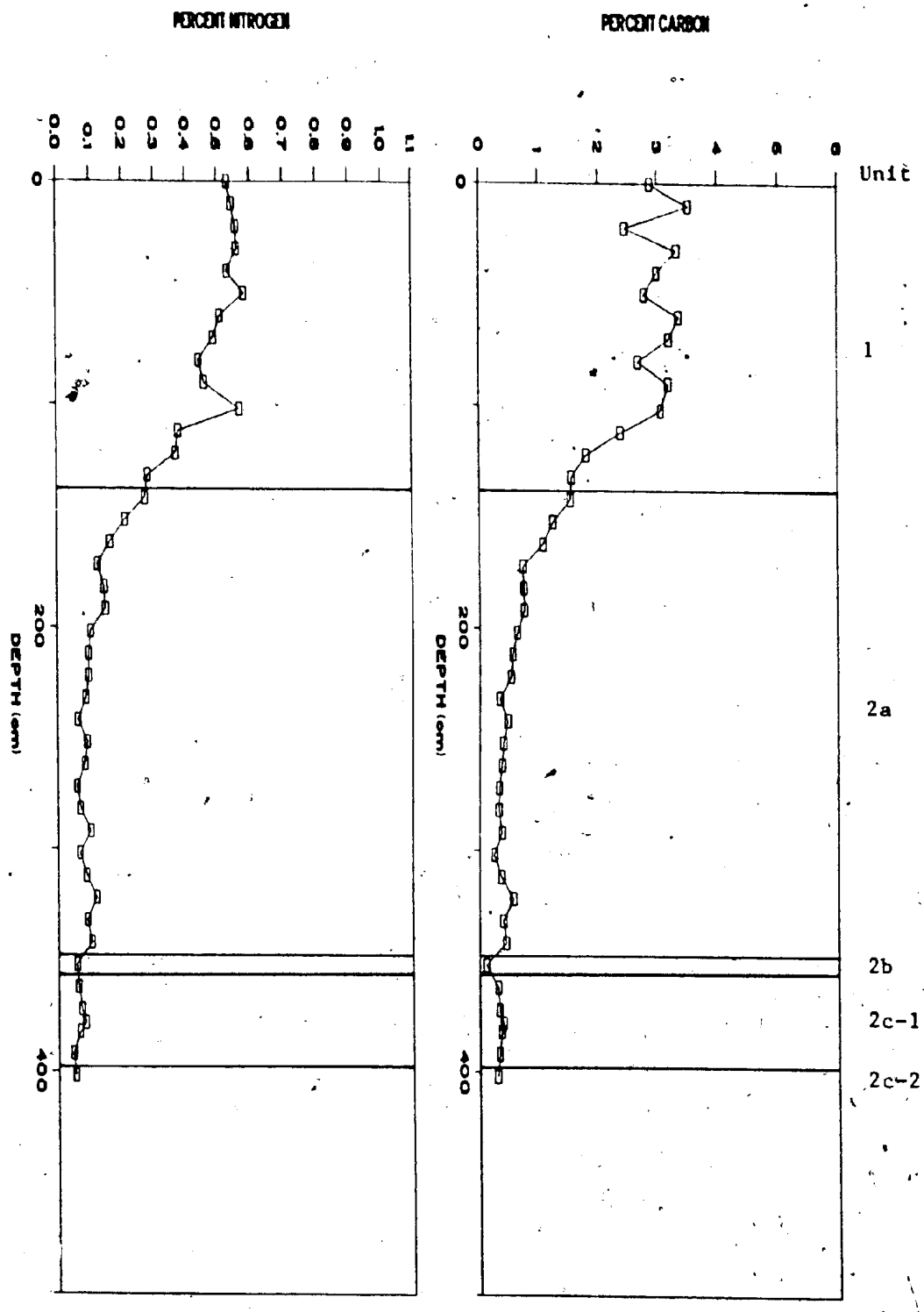

PERCENT NITROGEN
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
PERCENT CARBON
0
1
2
3
4
5
6
0
200
400
DEPTH (cm)
Unit
1
2a
2b
2c-1
2c-2

Figure 42. Carbon to nitrogen ratio data for core EX6.

C/N

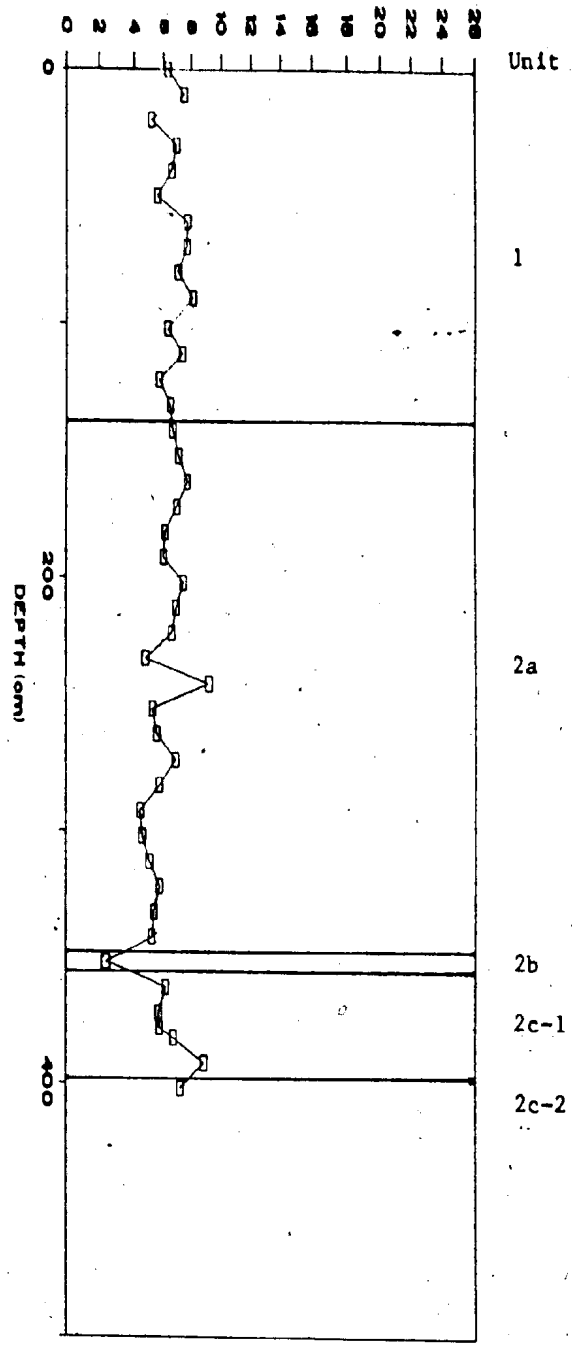
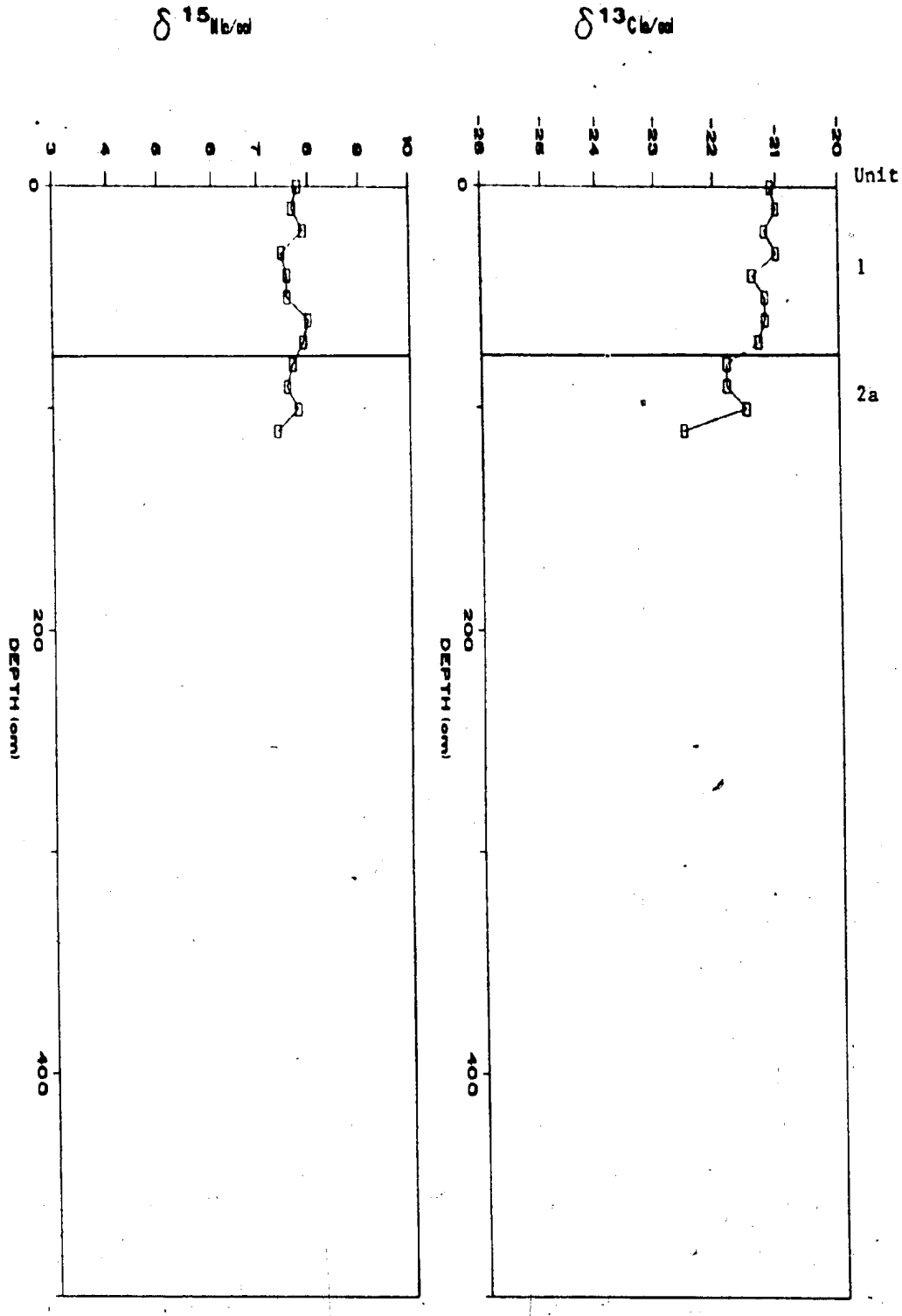


Figure 43. Carbon and nitrogen isotope data for core EXT6.


δ 15N (‰)
δ 13C (‰)
Unit
1
2a
DEPTH (cm)
0
200
400

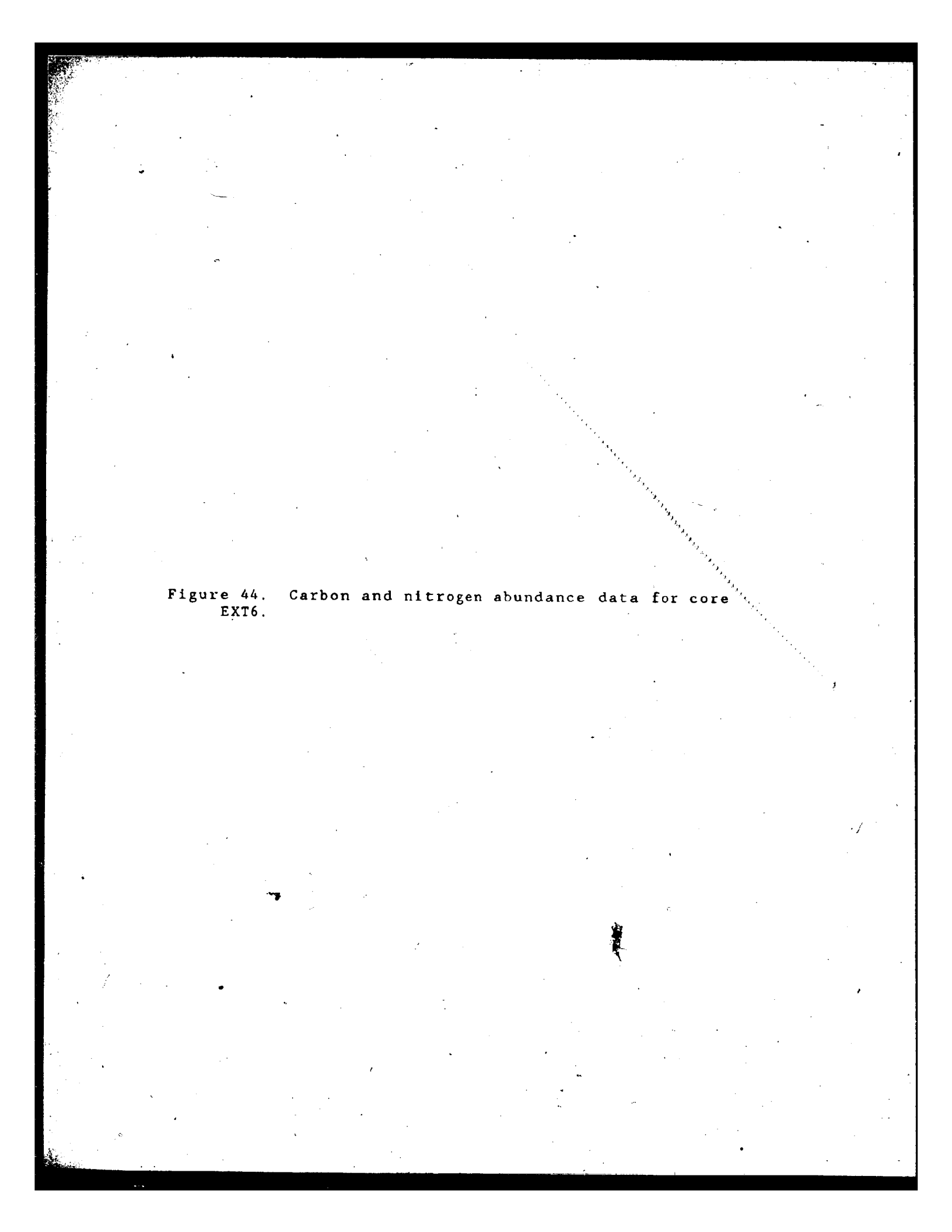


Figure 44. Carbon and nitrogen abundance data for core EXT6.

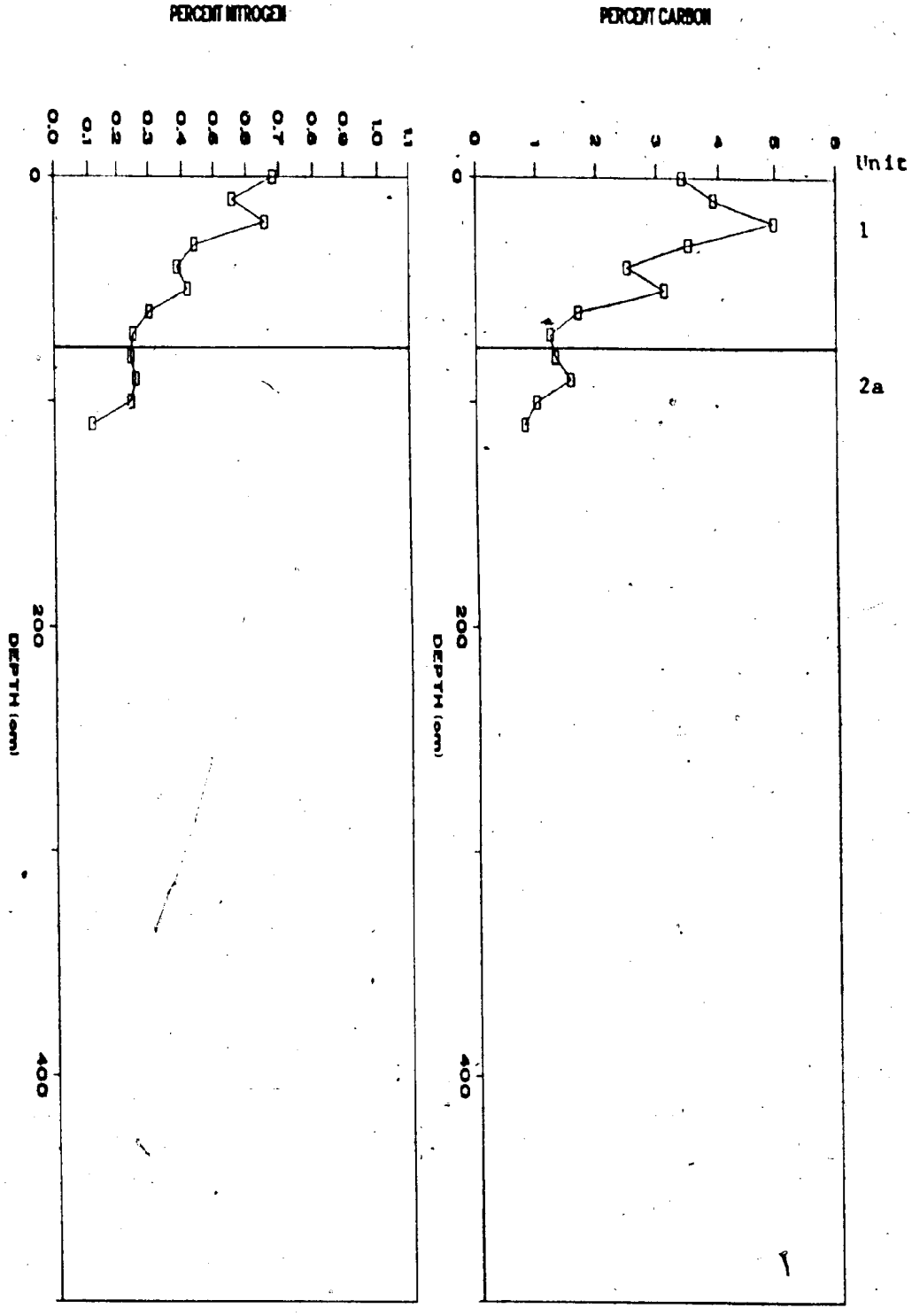

PERCENT NITROGEN
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
0
200
400
DEPTH (cm)
PERCENT CARBON
0
1
2
3
4
5
6
0
200
400
DEPTH (cm)
Unit
1
2a

Figure 45. Carbon to nitrogen ratio data for core EXT6.

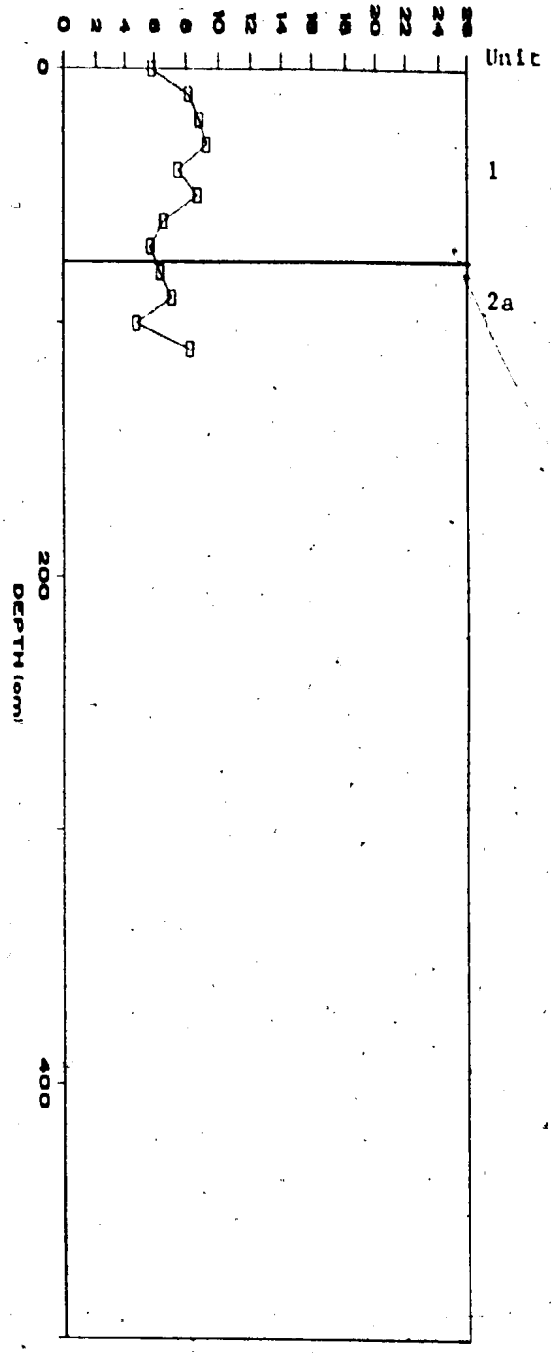

Unit
1
2a
0
200
400
DEPTH (cm)

Figure 46. Carbon and nitrogen isotope data for core ND2.

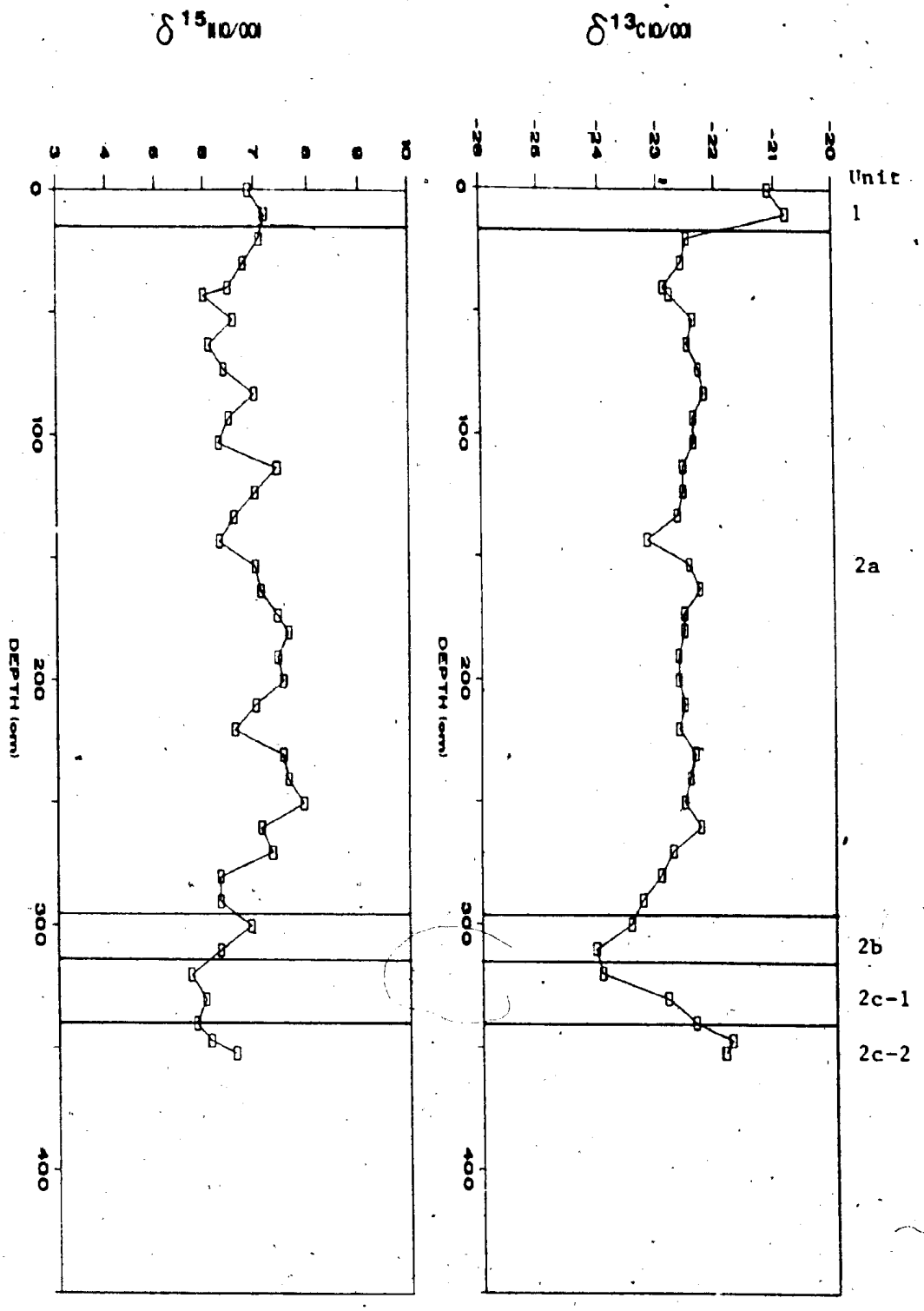

δ 15N‰
δ 13C‰
3 4 5 6 7 8 9 10
-26 -25 -24 -23 -22 -21 -20
0
100
200
300
400
DEPTH (cm)
Unit
1
2a
2b
2c-1
2c-2

Figure 47. Carbon and nitrogen abundance data for core ND2.

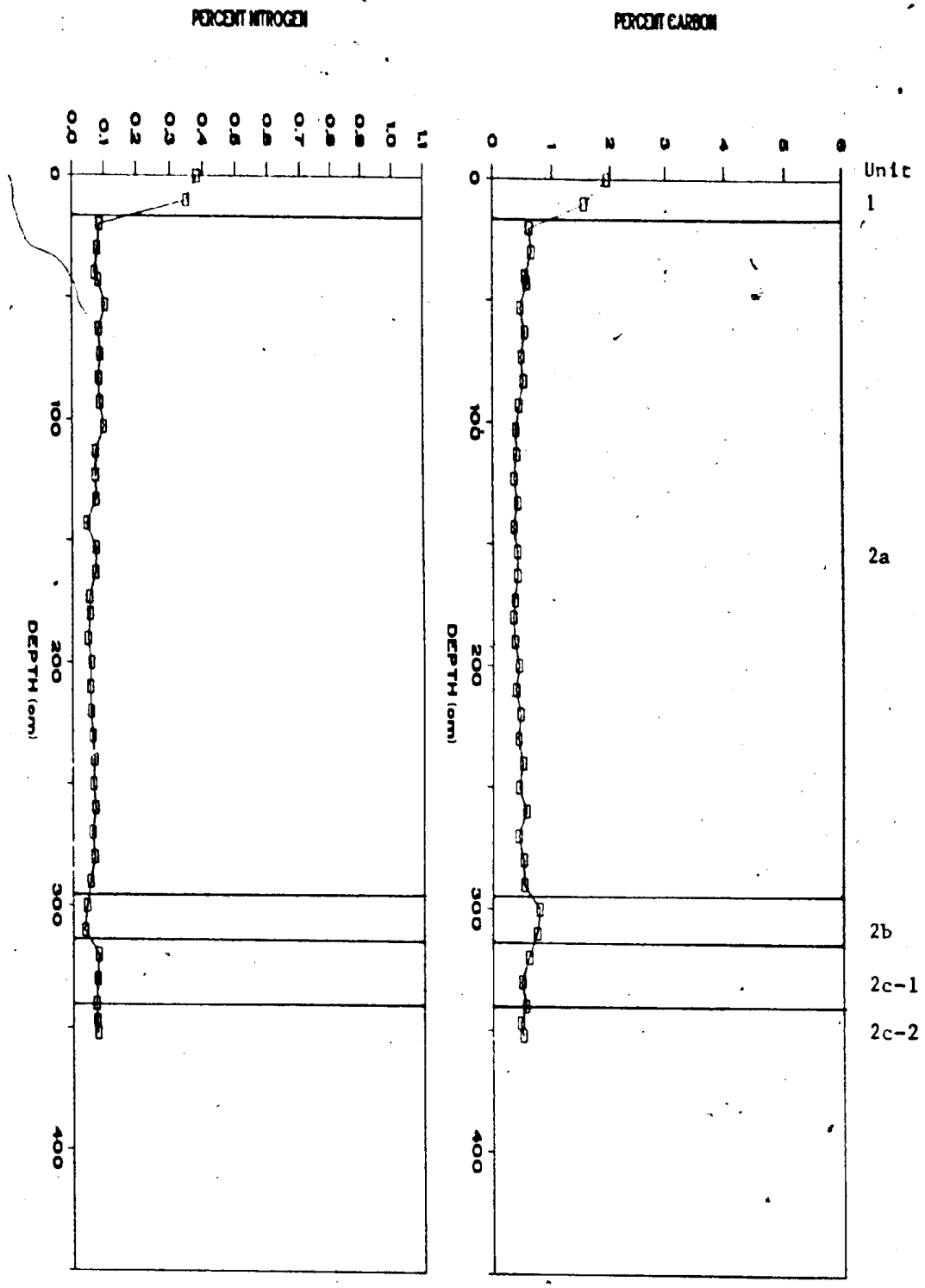
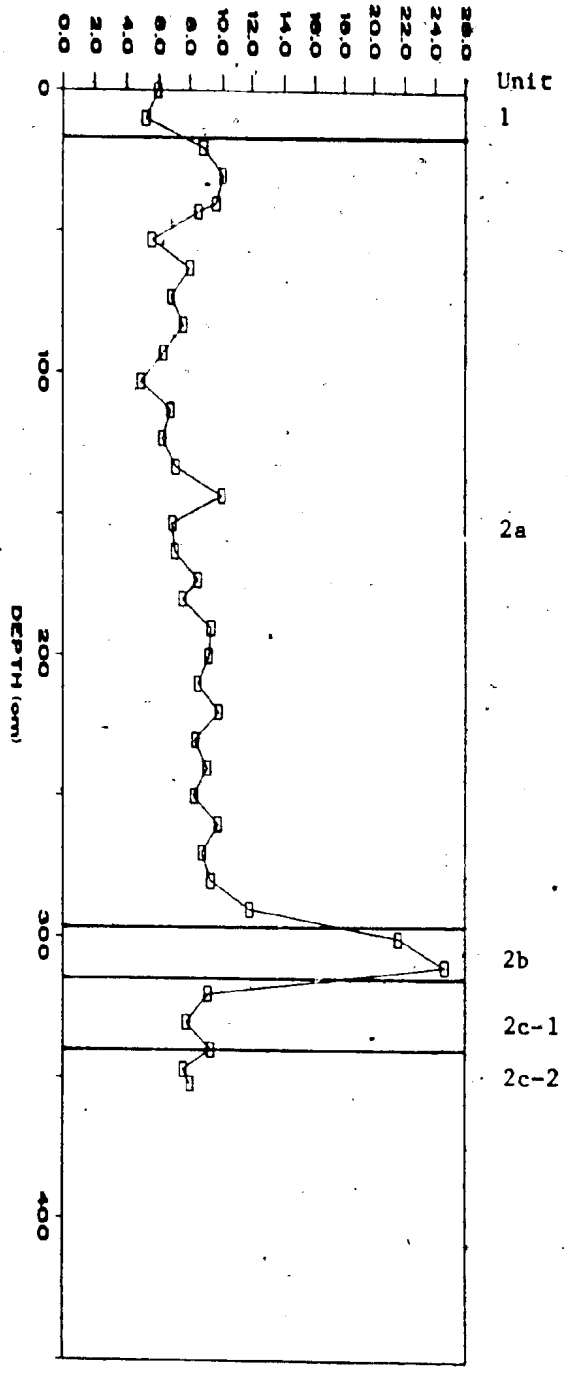

PERCENT NITROGEN
PERCENT CARBON
DEPTH (cm)
0
100
200
300
400
Unit
1
2a
2b
2c-1
2c-2

Figure 48. Carbon to nitrogen ratio data for core ND2.

C/N


0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
0
100
200
300
400
DEPTH (cm)
Unit
1
2a
2b
2c-1
2c-2

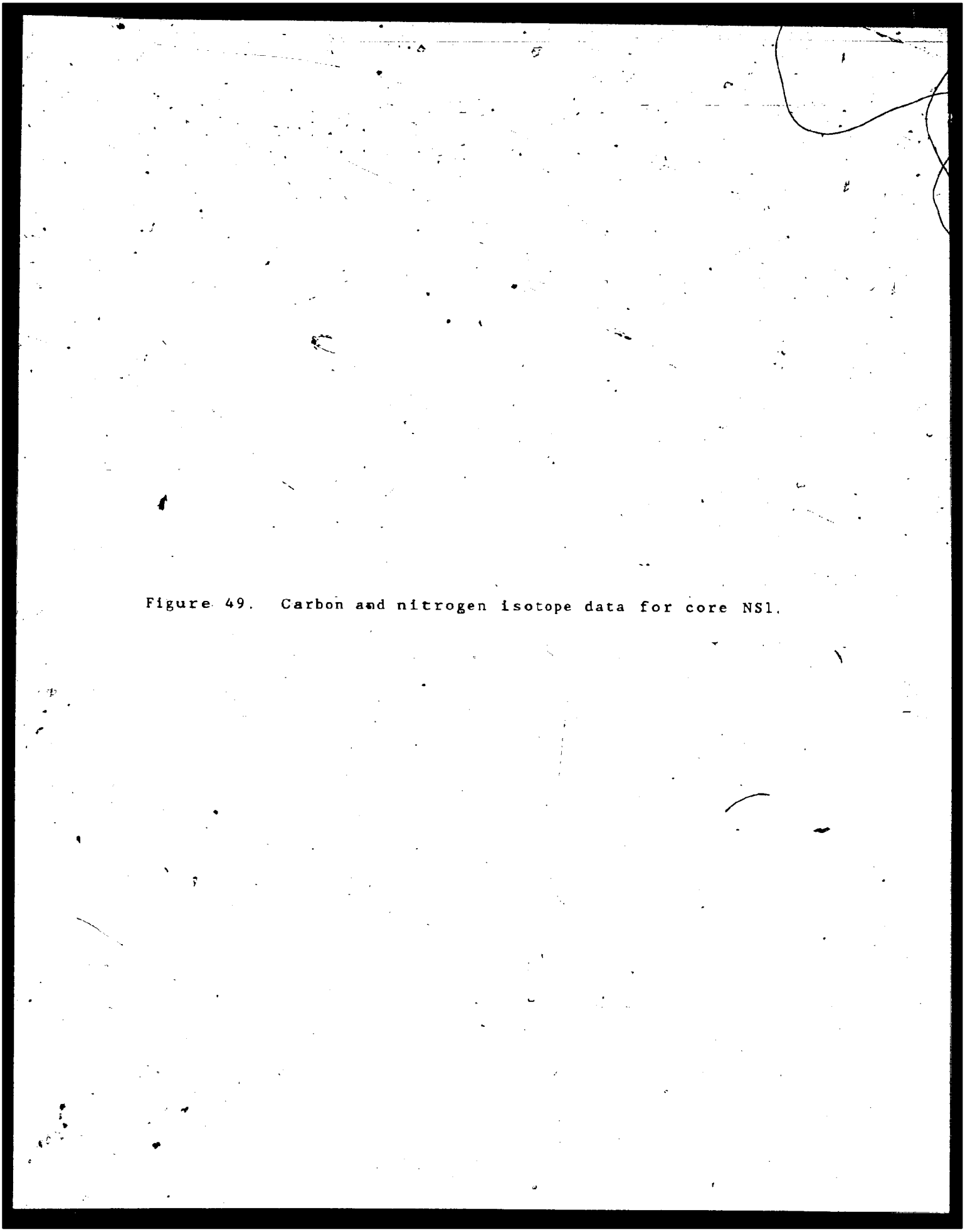


Figure 49. Carbon and nitrogen isotope data for core NS1.

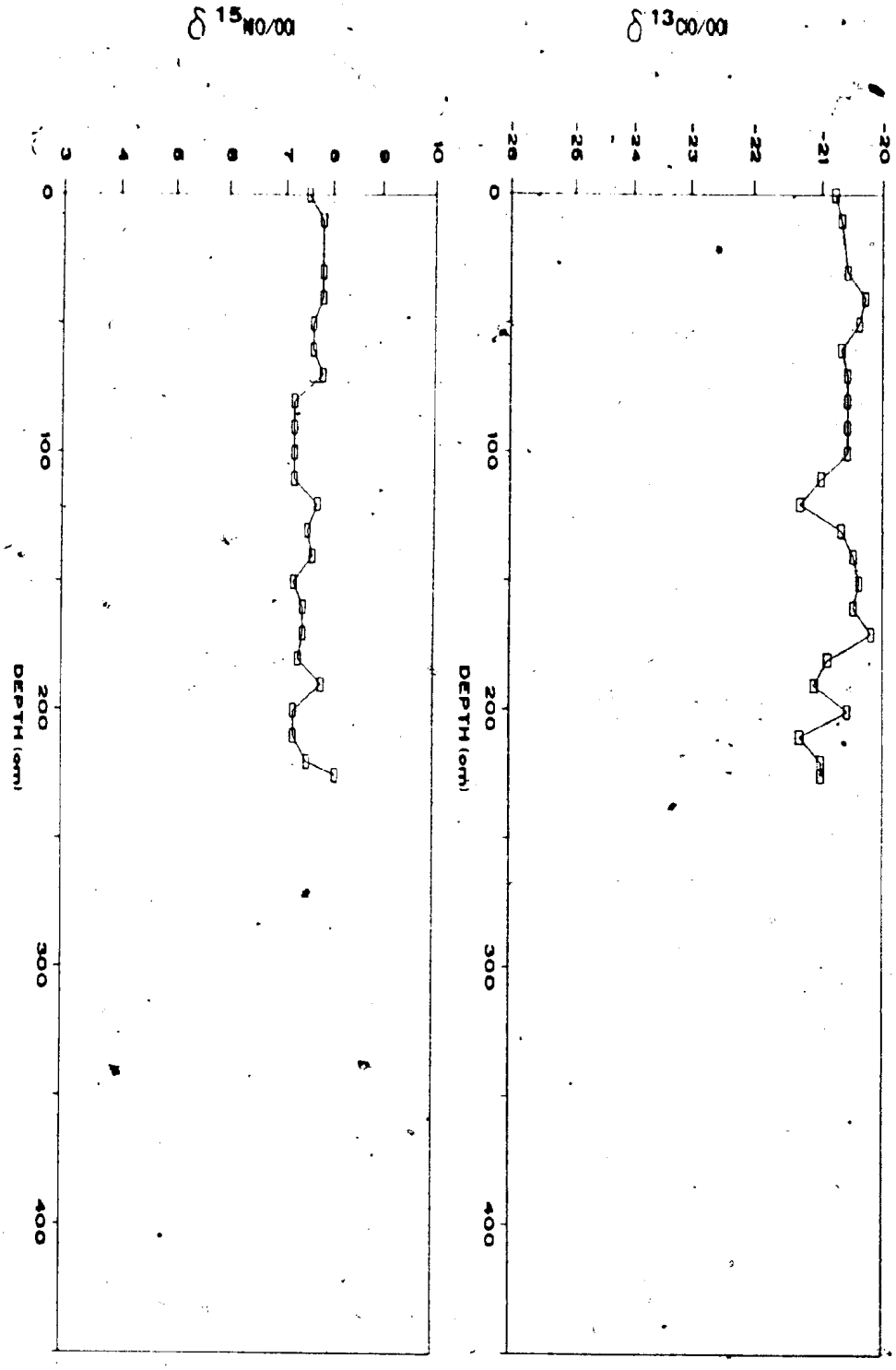

δ 15NO/00
δ 13CO/00
3 4 5 6 7 8 9 10
-20 -21 -22 -23 -24 -25 -26
0
100
200
300
400
DEPTH (cm)

Figure 50. Carbon and nitrogen abundance data for core NS1.

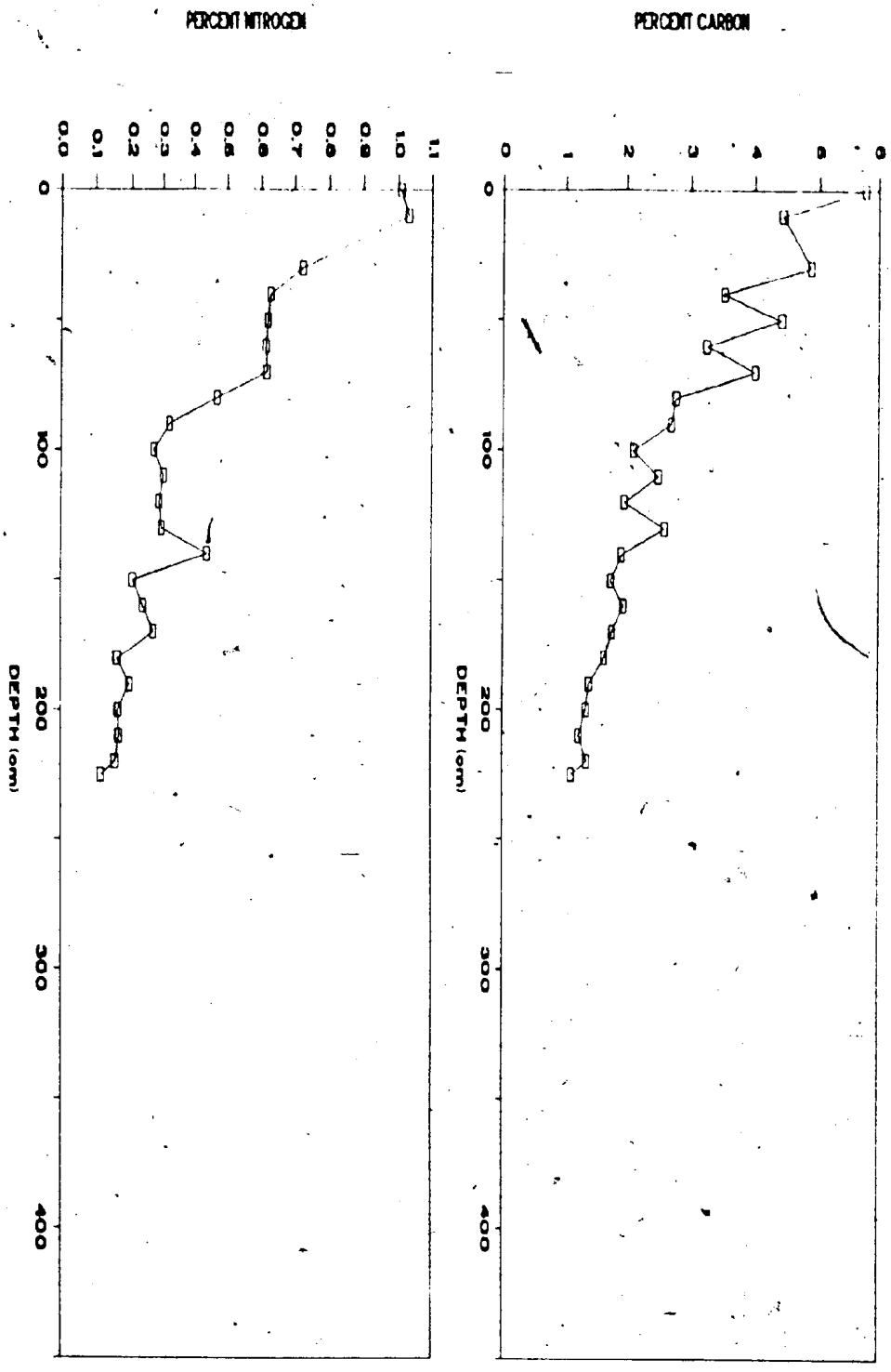

PERCENT NITROGEN
PERCENT CARBON
DEPTH (cm)
0
100
200
300
400

Figure 51. Carbon to nitrogen ratio data for core NS1.

C/N

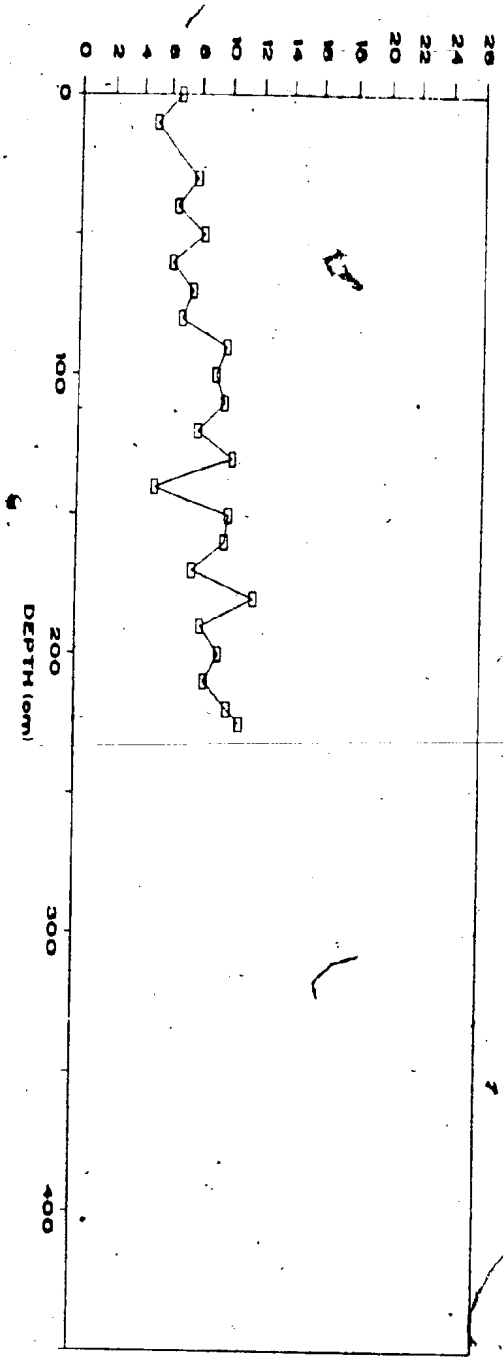


Figure 52. Carbon and nitrogen isotope data for core BB1.

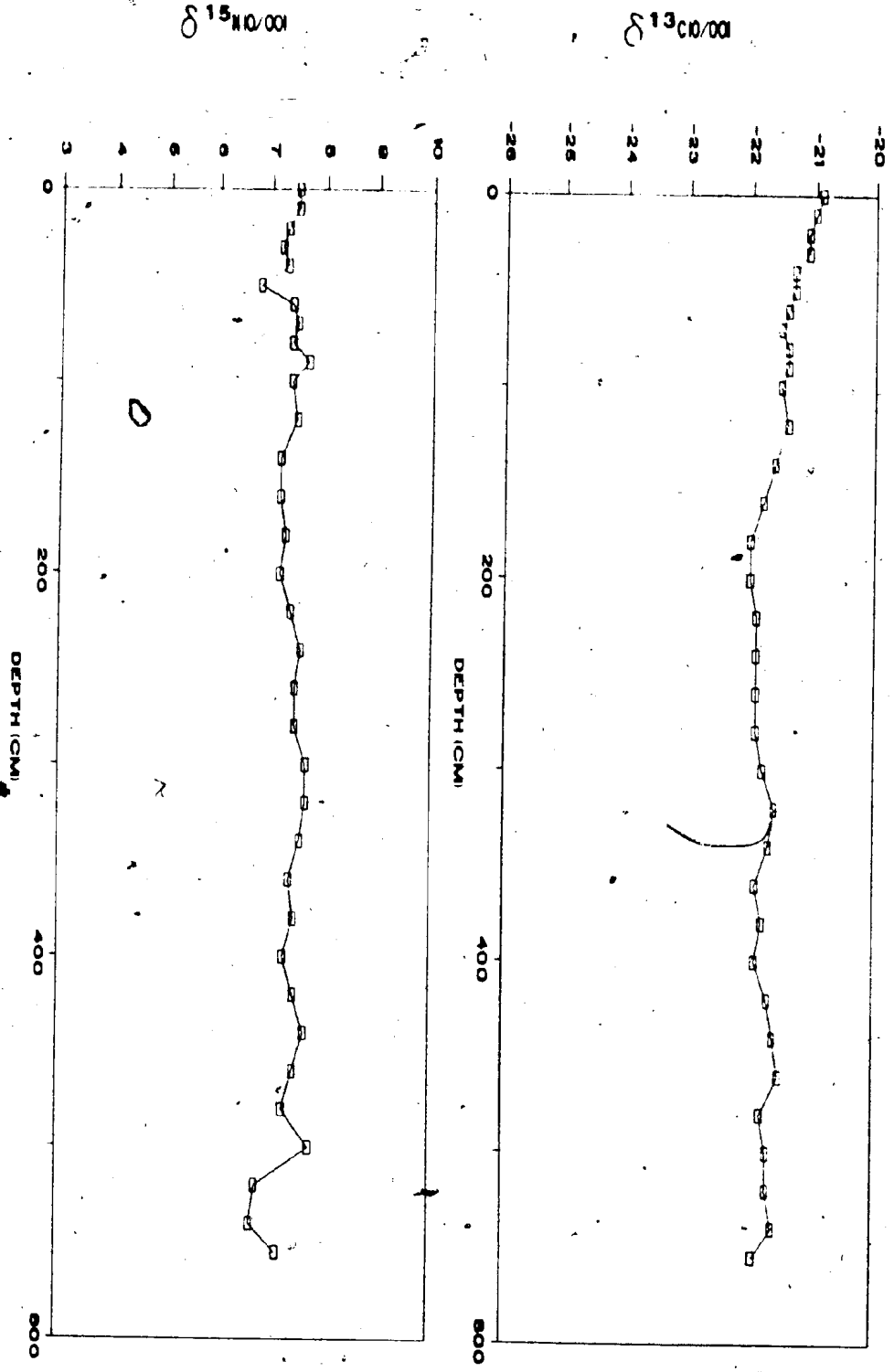
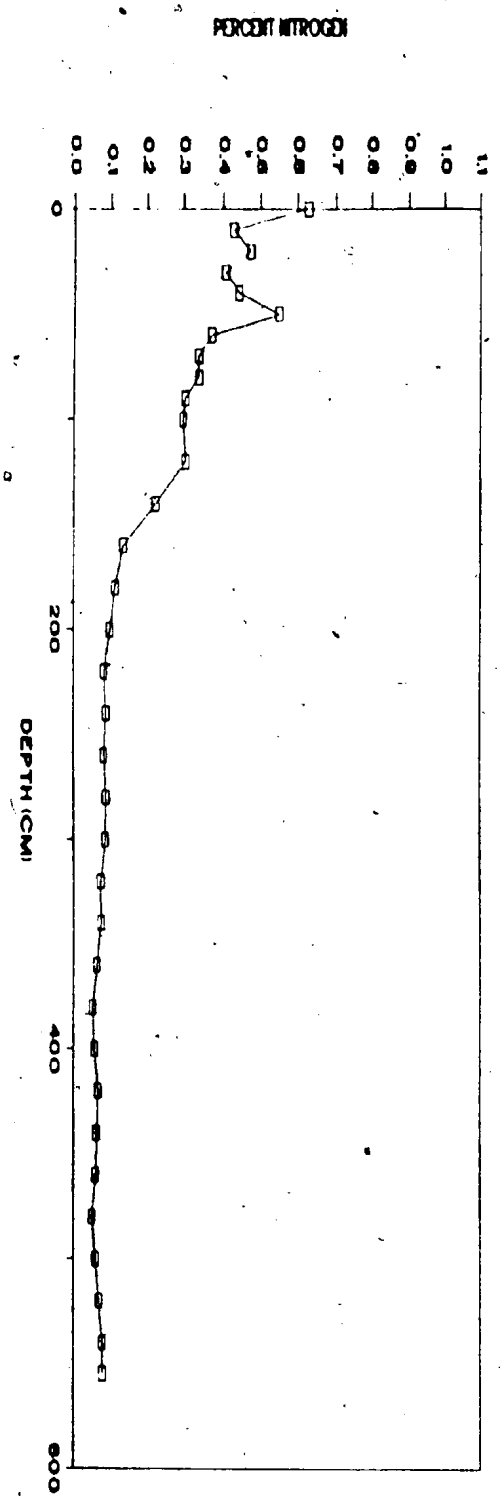

δ15N‰
δ13C‰
DEPTH (CM)
DEPTH (CM)
0
200
400
600
3
4
5
6
7
8
9
10
-26
-25
-24
-23
-22
-21
-20

Figure 53. Carbon and nitrogen abundance data for core BB1.


PERCENT NITROGEN
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
0
200
400
600
DEPTH (CM)

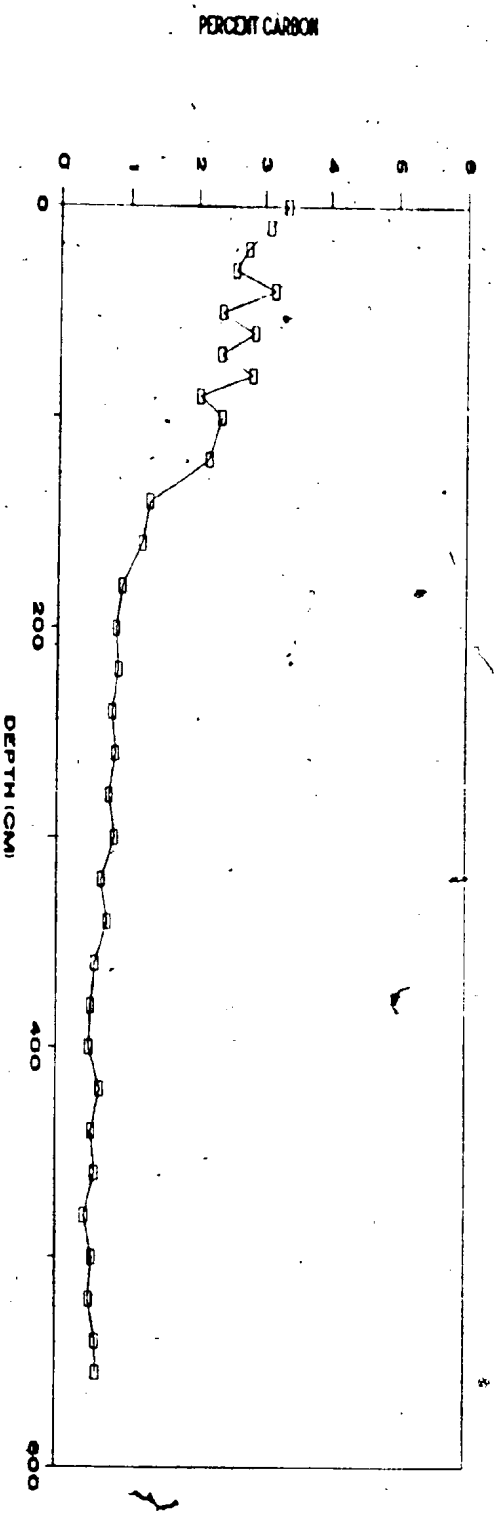
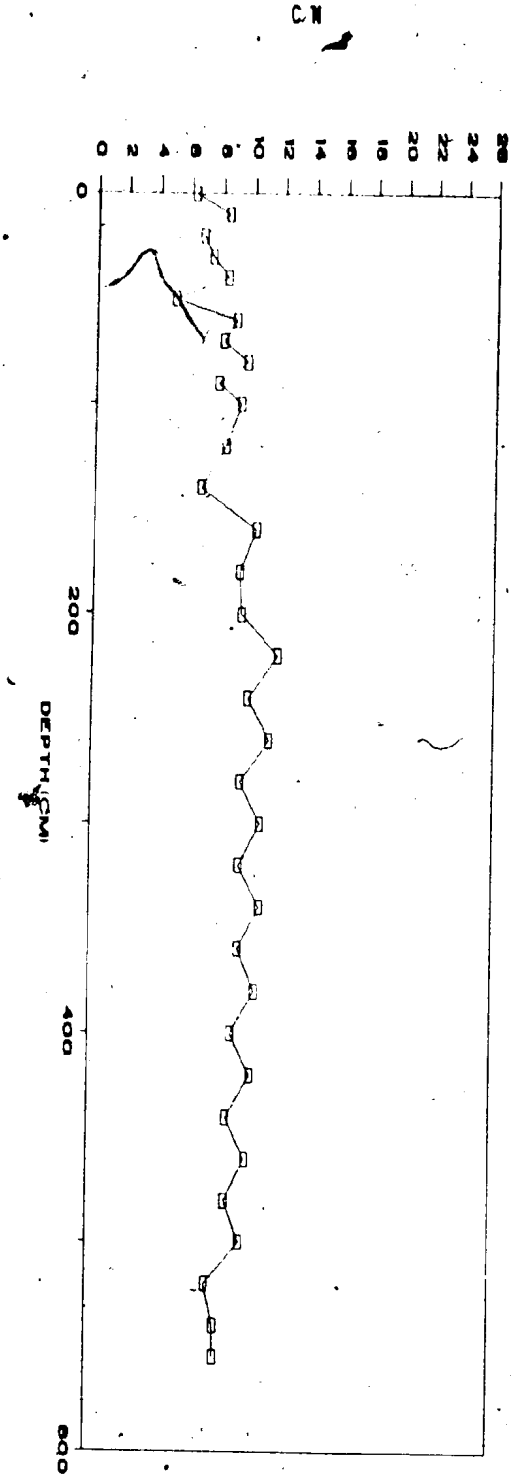

PERCENT CARBON
0
200
400
600
DEPTH (CM)

Figure 54. Carbon to nitrogen ratio data for core BB1.


CM
0
200
400
600
DEPTH (CM)

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Appendix 1. Latitude (lat.) and longitude (long.) coordinates of sampling stations, type of sample collected and research cruise of sample collection.

Station	lat.(N)	long.(W)	Core	DIC	Grab			POM*	
				D86	D86	B87	D87	T86	B87	D87
WB1	49 35.3	56 48.1	X	X			X	X	X	X
WB6	50 02.2	56 29.7							X	X
WB7	50 02.8	56 31.1	X	X				X		
WB8	50 09.5	56 19.7					X			
GI1	50 33.0	52 27.4					X			
GI2	50 44.9	55 10.5					X			
SB2	50 17.4	55 32.8							X	X
SB3	50 16.0	55 27.0	X							
SB4	50 14.7	55 17.9		X				X		
ND2	49 47.5	55 11.7	X	X			X	X	X	X
GB1	49 37.3	56 09.0		X			X	X		
GB2	49 38.6	56 06.5	X							
GB3	49 40.7	56 03.2								X
GB4	49 43.6	55 57.1					X			
HB1	49 26.9	56 05.1				X		X		
HB2	49 28.8	56 02.6	X							
HB3	49 30.5	56 00.3		X					X	
HB4	49 33.6	55 52.0				X				
HB5	49 38.4	55 44.4				X				
EX1	49 09.9	55 18.8		X	X	X			X	
EX2	49 13.7	55 15.8				X	X		X	X
EX3	49 17.7	55 12.4				X			X	X
FX4	49 22.2	55 10.3					X		X	X
EX6	49 30.6	55 07.4	X	X			X	X	X	X
BB1	48 45.1	53 21.6	X						X	
NS1	48 36.0	53 47.8	X					X		
TB5	48 03.1	53 21.1							X	X
TB6	48 08.2	53 10.8							X	X
RS5	48 01.5	53 55.0					X			
RS6	48 01.2	53 50.0								X
CB1	47 30.7	55 07.4					X			
CB2	47 36.7	53 07.1					X			
CB3	47 41.8	53 03.8					X			X
CB4	47 48.3	52 56.8					X			
CB5	47 53.2	52 44.3					X			

* D86 - Dawson Aug. 28 - Sept. 10, 1986; T86 - Templeman Nov. 15 - 22, 1986; B87 - Baffin May 22 - 30, 1987; D87 - Dawson Aug 10 - 15, 1987.

Appendix 2. Oxygen and dissolved inorganic carbon data for the Dawson 1986 cruise.

Sta.*	depth (m)	$\delta^{13}C$ DIC (°/oo)	conc. (mM/kg)	O_2 (ml/l)	O_2 sat. (%)	sal. (°/oo)	temp. (°C)	date (m/d/yr)
WB1	10	-1.9	0.944	6.6	102	30.6	10.2	9/4/86
	100	0.0	1.012	7.6	103	31.6	4.0	
	237	-5.6	2.089	7.0	91	33.2	-1.0	
WB7	10	-3.7	1.975	6.6	103	31.1	10.0	9/4/86
	80	-1.4	1.932	7.8	106	31.9	4.0	
	400	-4.7	1.475	6.5	80	33.9	0.0	
ND2	1	-1.3	1.975	6.6	103	30.7	10.6	9/7/86
	40	-2.3	1.787	7.4	102	31.2	4.8	
	131	**	**	7.4	87	32.9	-1.4	
	356	-3.5	1.882	6.1	79	34.5	2.2	
SB4	14	-3.7	1.523	6.6	101	31.3	9.7	9/5/86
	82	-6.9	1.714	7.3	86	32.9	-1.4	
	300	**	1.637	6.5	81	33.9	0.3	
GB1	2	-0.7	0.879	6.4	101	30.8	11.0	9/7/86
	59	-5.7	1.844	7.5	98	30.8	3.0	
	207	-6.9	1.021	6.8	83	33.1	0.5	
HB3	2	-4.6	1.511	6.8	106	30.8	10.3	9/6/86
	22	-5.1	1.744	7.3	112	31.2	9.8	
	46	-5.7	1.801	7.3	111	32.8	9.1	
	189	-8.5	2.000	6.3	75	33.6	-0.8	
EX6	1	-3.0	1.621	6.6	102	30.6	10.8	9/6/86
	60	-6.5	1.657	7.7	102	31.9	3.0	
	626	-7.4	1.658	6.8	80	33.3	-1.6	
EX1	6	-5.7	1.307	6.9	108	25.0	11.9	9/5/86
	44	-5.6	1.719	6.6	86	31.5	2.5	
NS1	2	***	***	6.3	103	31.0	12.8	9/8/86
	31	***	***	6.6	98	31.7	8.5	
	221	***	***	6.3	79	33.6	0.1	

* Station locations are given in appendix 1.
** Sample was lost in handling.
*** DIC samples were not collected at this station.

Appendix 3. Oxygen data for the Baffin 1987 and the Dawson 1987 cruises.

Cruise	Stn	lat.(N) long.(W)	depth (m)	O_2 (ml/l)	O_2 sat. (%)	sal. (°/oo)	temp. (°C)	date (m/d/yr)
B87	WB5	49 58.5	6	7.9	103	31.1	3.1	5/27/87
		56 35.3	100	7.2	85	32.8	-1.5	
			464	6.4	80	34.0	0.4	
B87	SB2	*	5	7.9	102	31.8	2.6	5/26/87
			100	7.6	90	32.7	-1.7	
			277	7.2	89	33.8	-0.1	
B87	ND4	49 53.2	5	7.8	101	32.0	1.8	5/25/87
		54 41.9	100	6.6	78	32.8	-1.6	
D87	ND4		9	8.3	131	30.1	11.5	8/15/87
			53	10.0	124	32.1	0.8	
			103	9.6	115	32.8	-1.1	
			155	9.4	110	33.2	-1.3	
			201	9.4	112	33.5	-1.2	
			301	8.2	103	33.9	0.3	
			340	6.8	88	34.4	1.9	
D87	ND6	50 03.1	5	10.1	158	30.1	11.0	8/15/87
		54 15.5	49	4.1	50	32.7	-0.1	
			100	6.4	75	33.2	-1.3	
			154	4.8	57	33.7	-1.0	
			204	5.0	61	34.0	-0.2	
			303	6.2	80	34.4	1.6	
			352	7.9	103	34.5	2.2	
D87	GB3	*	8	7.1	119	31.1	14.2	8/14/87
			54	9.9	123	32.4	0.4	
			103	9.6	113	32.8	-1.3	
			204	9.0	108	33.5	-0.9	
			305	8.5	107	34.0	0.7	
			384	8.0	101	34.1	0.8	
D87	EX5	49 26.3	7	7.8	131	30.1	14.6	8/14/87
		55 07.8	102	9.4	110	33.1	-1.6	
			201	8.9	105	33.2	-1.4	
			303	8.7	104	33.3	-1.2	
			404	8.6	103	33.3	-1.0	
			505	8.9	106	33.3	-1.1	
			593	9.0	108	33.3	-1.1	

* Station locations given in Appendix 1.

Appendix 3. Continued.

Cruise	Stn	lat.(N) long.(W)	depth (m)	O_2 (ml/l)	O_2 sat. (%)	sal. (°/oo)	temp. (°C)	date (m/d/yr)
B87	EX6	*	5	8.4	112	28.1	4.5	5/25/87
			100	7.5	87	32.6	-1.5	
			620	7.2	86	33.3	-0.9	
D87	EX6		5	7.2	120	30.6	13.5	8/14/87
			100	8.5	102	32.6	-1.2	
			200	8.7	104	33.2	-0.9	
			300	8.8	105	33.3	-1.1	
			400	8.3	100	33.4	-1.2	
			500	7.4	89	33.4	-1.2	
			620	9.6	115	33.4	-1.2	
B87	HB4	*	5	8.3	110	30.7	3.7	5/26/87
			200	7.6	90	32.6	-1.0	
			431	5.8	71	33.6	-0.1	
B87	BB2	49 45.0	5	7.9	101	31.9	1.9	5/24/87
		53 22.0	100	6.7	79	32.9	-1.7	
			294	6.7	85	34.0	0.8	
D87	TB3	47 49.3	9	8.1	137	31.1	14.2	8/12/87
		53 34.4	53	10.0	126	32.4	0.8	
			103	9.7	116	32.8	-0.9	
			153	9.3	110	33.0	-1.4	
			200	8.5	102	33.3	-0.9	
			300	7.9	100	34.0	1.0	
			396	7.8	99	34.2	1.2	
D87	TB4	47 54.8	5	8.4	140	31.2	13.6	8/12/87
		53 28.9	50	10.4	129	32.4	0.4	
			150	9.5	112	33.0	-1.3	
			400	7.9	100	34.2	1.2	
			525	7.9	101	34.2	1.4	
B87	TB7	48 13.5	5	8.2	105	32.1	2.0	5/24/87
		52 58.4	100	7.4	86	33.1	-1.9	
			293	6.3	80	34.1	1.1	
D87	CB6	48 00.0	7	7.4	128	31.6	14.9	8/10/87
		52 33.4	53	9.9	119	33.2	-0.6	
			102	9.3	110	33.7	-1.6	
			153	9.5	116	33.8	-1.7	
			182	7.6	90	34.1	-1.3	

Appendix 4. Grain-size data for core SB3.

Depth(cm)	% Sand	% Silt	% Clay
29	7.6	64.3	28.1
55	6.2	62.8	31.0
79	3.4	48.9	47.6
105	12.4	52.4	35.2
129	10.2	53.9	35.9
155	29.6	45.9	24.5
179	13.4	45.6	41.0
205	1.6	48.7	49.7
229	1.6	43.9	54.5
255	3.0	35.9	61.1
279	3.7	53.0	43.3
305	7.0	49.6	43.4
329	2.7	37.6	59.7
355	13.5	55.4	31.1
379	6.6	48.1	45.3
405	4.5	42.3	53.2
429	6.6	37.8	55.6
435	9.6	46.6	43.8
445	10.3	35.7	54.0
455	29.6	31.2	39.2
479	24.9	34.1	41.0
505	35.7	36.9	27.4
515	56.6	23.5	19.9

Appendix 5. Isotopic and elemental data of sediment cores collected in relation to depth below the core top.

Core	Depth (cm)	$\delta^{15}N$	$\delta^{13}C$	%C	%N	C/N
WB1	0	6.4	-23.7	4.83	0.30	19.03
WB1	10	6.9	-22.9	3.68	0.36	11.83
WB1	20	7.0	-22.0	3.05	0.36	9.98
WB1	30	6.9	-22.4	2.63	0.40	7.65
WB1	40	6.6	-22.1	3.58	0.43	9.77
WB1	50	6.9	-22.7	4.65	0.46	11.70
WB1	60	6.6	-22.2	3.40	0.40	9.95
WB1	70	6.5	-22.9	3.77	0.44	9.93
WB1	80	7.9	-22.7	3.55	0.46	9.08
WB1	90	7.7	-22.8	2.91	0.43	7.88
WB1	100	7.0	-22.7	2.96	0.41	8.50
WB1	120	6.8	-23.0	3.80	0.36	12.29
WB1	140	7.3	-22.6	3.56	0.43	9.56
WB1	160	7.2	-23.6	2.17	0.37	6.90
WB1	180	7.0	-23.9	2.63	0.38	8.17
WB1	200	7.6	-22.3	2.76	0.43	7.54
WB1	220	7.0	-24.8	2.15	0.39	6.50
WB1	244	7.9	-24.7	1.14	0.27	5.03
WB1	264	7.7	-24.6	1.46	0.29	5.82
WB1	284	7.8	-24.7	1.21	0.27	5.23
WB1	304	8.0	-24.4	1.84	0.36	6.03
WB1	314	7.4	-24.4	2.00	0.35	6.77
WB1	344	7.3	-22.8	2.98	0.39	8.91
WB1	364	7.6	-22.8	2.48	0.42	6.84
WB1	388	7.9	-23.0	1.62	0.26	7.36
WB1	408	8.7	-23.2	1.30	0.17	9.17
WB1	428	8.7	-23.9	1.25	0.20	7.22
WB1	448	8.8	-22.6	1.75	0.25	8.02
WB1	458	9.2	-22.3	0.89	0.25	4.13
WB1	468	8.3	-22.3	1.42	0.49	3.39
WB1	478	8.6	-22.9	1.51	0.19	9.12
WB1	488	9.3	-22.7	1.26	0.13	11.79
WB1	508	8.7	-23.6	0.99	0.18	6.26
WB1	528	9.0	-23.2	1.16	0.15	9.05
WB7	0	6.9	-21.5	2.78	0.55	5.87
WB7	10	6.9	-21.3	2.78	0.43	7.58
WB7	20	7.1	-21.6	2.64	0.50	6.20
WB7	30	7.1	-21.2	2.15	0.60	4.20
WB7	40	7.1	-21.6	2.48	0.45	6.47
WB7	50	6.9	-21.7	2.00	0.40	5.84

Appendix 5. Continued.

Core	Depth (cm)	$\delta^{15}N$	$\delta^{13}C$	%C	%N	C/N
WB7	60	6.7	-22.2	1.86	0.50	4.38
WB7	70	7.4	-21.7	2.33	0.58	4.67
WB7	80	7.8	-21.7	2.23	0.50	5.23
WB7	90	6.7	-22.5	2.48	0.56	5.20
WB7	100	7.9	-21.7	2.01	0.50	4.66
WB7	110	7.6	-21.8	2.68	0.50	6.27
WB7	120	7.3	-21.7	2.43	0.62	4.58
WB7	123	7.2	-21.6	1.97	0.40	5.45
WB7	133	7.9	-21.7	2.03	0.38	6.25
WB7	143	7.4	-21.8	2.03	0.48	4.90
WB7	153	7.0	-22.1	2.35	0.47	5.84
WB7	163	7.3	-22.0	1.75	0.44	4.61
WB7	173	6.7	-22.4	1.73	0.29	7.03
WB7	183	7.3	-22.4	0.99	0.26	4.38
WB7	193	6.8	-22.5	1.16	0.27	5.09
WB7	203	6.4	-22.7	1.19	0.17	8.07
WB7	213	7.6	-22.4	0.95	0.10	11.26
WB7	223	6.9	-23.0	0.68	0.11	7.18
WB7	233	8.3	-22.9	0.55	0.08	8.04
WB7	243	7.8	-22.8	0.52	0.12	4.98
WB7	253	7.4	-23.4	0.53	0.11	5.83
WB7	263	7.5	-23.1	0.51	0.09	6.98
WB7	273	8.1	-23.3	0.42	0.11	4.48
WB7	280	6.9	-23.0	0.54	0.09	6.71
WB7	290	7.7	-23.2	0.52	0.05	11.87
WB7	300	8.1	-22.9	0.51	0.07	8.39
WB7	310	8.0	-22.9	0.40	0.08	5.84
WB7	320	7.0	-22.6	0.52	0.11	5.71
WB7	330	7.6	-23.8	0.56	0.12	5.32
WB7	340	7.5	-22.9	0.41	0.10	4.98
WB7	350	6.8	-23.1	0.38	0.09	5.23
WB7	360	7.7	-23.5	0.48	0.12	4.86
WB7	370	7.4	-22.3	0.40	0.09	5.46
WB7	380	6.0	-23.2	0.40	0.08	5.93
WB7	390	6.2	-23.2	0.35	0.18	2.30
WB7	400	8.6	-23.7	0.41	0.06	7.74
WB7	410	9.7	-23.7	0.45	0.17	3.02
WB7	420	8.3	-24.2	0.44	0.09	5.86
WB7	429	8.2	-24.7	0.40	0.10	4.71
SB3	0	8.1	-22.6	1.13	0.32	4.17
SB3	10	8.0	-22.4	1.09	0.34	3.74

Appendix 5. Continued.

Core	Depth (cm)	$\delta^{15}N$	$\delta^{13}C$	%C	%N	C/N
SB3	20	7.0	-22.5	1.10	0.21	6.07
SB3	30	6.8	-22.5	1.53	0.21	8.44
SB3	40	8.3	-22.7	0.79	0.19	4.84
SB3	50	7.7	-23.1	0.91	0.15	6.97
SB3	60	6.9	-23.2	0.66	0.33	2.34
SB3	70	8.2	-24.4	0.63	0.14	5.33
SB3	80	6.9	-24.0	0.57	0.13	4.93
SB3	90	6.8	-23.9	0.62	0.12	5.84
SB3	100	8.3	-24.3	0.62	0.11	6.65
SB3	110	7.4	-23.9	0.49	0.18	3.09
SB3	120	8.7	-23.9	0.53	0.11	5.92
SB3	130	7.7	-24.2	0.42	0.10	5.12
SB3	140	8.1	-24.3	0.52	0.21	2.94
SB3	150	6.4	-24.6	0.40	0.15	3.21
SB3	160	6.5	-24.9	0.45	0.14	3.70
SB3	170	6.1	-24.9	0.08	0.06	1.71
SB3	180	5.5	-24.4	0.37	0.14	2.98
SB3	190	6.5	-23.1	0.52	0.12	5.00
SB3	200	6.0	-21.9	0.61	0.14	5.20
SB3	210	6.9	-22.3	0.63	0.10	7.19
SB3	220	7.8	-22.1	0.64	0.15	4.90
SB3	230	7.8	-22.5	0.57	0.36	1.89
SB3	240	7.4	-22.0	0.58	0.12	5.61
SB3	250	7.5	-22.5	0.60	0.12	5.70
SB3	260	8.4	-21.8	0.75	0.17	5.12
SB3	270	7.0	-21.9	0.74	0.18	4.69
SB3	280	9.2	-22.4	0.71	0.17	4.85
SB3	290	8.6	-22.2	0.87	0.22	4.60
SB3	300	7.4	-21.8	0.89	0.19	5.38
SB3	310	8.0	-22.5	0.68	0.18	4.45
SB3	320	7.3	-22.6	0.76	0.19	4.65
SB3	330	8.0	-23.0	0.68	0.16	4.87
SB3	340	7.6	-23.2	0.76	0.23	3.89
SB3	350	6.4	-22.9	0.55	0.17	3.77
SB3	360	6.0	-23.4	0.56	0.13	5.11
SB3	370	6.8	-22.5	0.40	0.12	4.03
SB3	380	6.2	-23.0	0.52	0.10	5.90
SB3	390	6.2	-23.4	0.43	0.09	5.59
SB3	400	4.2	-23.5	0.45	0.11	4.62
SB3	410	3.5	-25.1	0.31	0.03	12.43
SB3	413	4.1	-25.3	0.66	0.14	5.41
SB3	420	3.6	-23.6	0.52	0.11	5.44

Appendix 5. Continued.

Core	Depth (cm)	$\delta^{15}N$	$\delta^{13}C$	%C	%N	C/N
SB3	430	6.1	-23.6	0.46	0.11	4.81
SB3	440	6.3	-23.8	0.54	0.10	6.21
SB3	450	4.6	-23.7	0.44	0.08	6.77
SB3	460	4.7	-24.2	0.24	0.06	4.73
SB3	470	4.6	-23.3	0.17	0.05	4.13
SB3	480	5.0	-23.6	0.18	0.06	3.40
SB3	490	4.6	-23.3	0.17	0.04	4.54
SB3	500	4.5	-23.6	0.16	0.03	7.18
SB3	510	4.0	-25.0	0.15	0.03	6.70
SB3	520	4.3	-25.5	0.14	0.04	4.29
SB3	525	4.6	-25.5	0.17	0.03	7.35
SB3	CC*	4.0	-25.0	0.13	0.03	5.38
EX6**	0	7.8	-21.1	3.41	0.68	5.83
EX6	10	7.7	-21.0	3.92	0.56	8.18
EX6	20	7.9	-21.2	4.99	0.66	8.84
EX6	30	7.5	-21.0	3.50	0.44	9.27
EX6	40	7.6	-21.4	2.49	0.39	7.51
EX6	50	7.6	-21.2	3.13	0.42	8.73
EX6	60	8.0	-21.2	1.72	0.30	6.62
EX6	70	7.9	-21.3	1.25	0.25	5.75
EX6	80	7.7	-21.8	1.33	0.24	6.38
EX6	90	7.6	-21.8	1.59	0.26	7.13
EX6	100	7.8	-21.5	1.01	0.25	4.82
EX6	110	7.4	-22.5	0.80	0.11	8.25
EX6***	0	7.5	-22.4	2.88	0.53	6.30
EX6	10	8.0	-22.3	3.51	0.53	7.48
EX6	20	7.6	-22.9	2.45	0.56	5.11
EX6	30	7.7	-21.7	3.33	0.56	6.92
EX6	40	7.4	-22.4	3.00	0.53	6.57
EX6	50	7.7	-22.7	2.77	0.53	5.54
EX6	60	7.3	-21.6	3.36	0.51	7.71
EX6	70	7.7	-21.4	3.21	0.49	7.66
EX6	80	7.6	-22.3	2.67	0.44	7.02
EX6	90	7.5	-21.2	3.20	0.45	8.13
EX6	102	7.8	-21.0	3.07	0.57	6.31
EX6	112	7.4	-21.2	2.38	0.38	7.36
EX6	122	7.6	-21.3	1.80	0.37	6.70

* CC - Core catcher
** Trigger weight core
*** Piston core

Appendix 5. Continued.

Core	Depth (cm)	$\delta^{15}N$	$\delta^{13}C$	%C	%N	C/N
EX6	132	7.7	-21.7	1.56	0.28	6.52
EX6	142	7.7	-21.8	1.54	0.27	6.68
EX6	152	7.2	-21.3	1.25	0.21	7.10
EX6	162	7.1	-22.2	1.08	0.16	7.72
EX6	172	6.8	-22.0	0.75	0.13	6.96
EX6	182	6.9	-22.0	0.76	0.15	6.12
EX6	192	7.1	-21.8	0.76	0.15	6.00
EX6	202	7.3	-21.7	0.65	0.10	7.44
EX6	212	7.3	-21.8	0.57	0.10	6.91
EX6	222	7.6	-21.6	0.54	0.10	6.62
EX6	232	7.2	-21.7	0.35	0.07	4.76
EX6	242	7.1	-21.8	0.48	0.06	9.26
EX6	252	6.5	-22.1	0.41	0.09	5.23
EX6	262	8.3	-22.1	0.39	0.08	5.51
EX6	272	6.8	-21.8	0.34	0.06	6.87
EX6	282	6.9	-22.0	0.33	0.07	5.70
EX6	292	7.9	-21.3	0.38	0.10	4.34
EX6	302	8.0	-22.8	0.26	0.07	4.53
EX6	312	6.9	-21.5	0.37	0.09	5.00
EX6	322	7.1	-22.1	0.58	0.12	5.70
EX6	332	6.2	-22.5	0.41	0.09	5.31
EX6	342	6.8	-22.3	0.46	0.10	5.16
EX6	352	6.9	-24.2	0.12	0.05	2.43
EX6	362	6.5	-22.3	0.32	0.05	6.13
EX6	372	6.3	-22.5	0.34	0.07	5.65
EX6	378	6.4	-22.2	0.41	0.08	5.68
EX6	382	6.8	-22.1	0.37	0.07	6.68
EX6	392	6.8	-22.4	0.34	0.04	8.87
EX6	402	4.9	-24.7	0.31	0.05	7.18
HB2	0	6.6	-22.4	2.44	0.33	8.60
HB2	10	6.0	-22.2	2.88	0.29	11.58
HB2	20	6.1	-22.5	2.87	0.44	7.67
HB2	30	6.5	-22.4	2.33	0.44	6.17
HB2	40	7.8	-22.4	1.87	0.31	7.12
HB2	50	7.8	-22.2	1.95	0.30	7.51
HB2	60	7.5	-21.9	2.04	0.31	7.58
HB2	70	6.4	-22.4	2.41	0.31	9.05
HB2	80	7.2	-21.8	2.05	0.23	10.28
HB2	90	7.8	-21.8	2.03	0.37	6.51
HB2	100	6.7	-21.8	1.97	0.18	12.67
HB2	110	7.3	-21.9	2.43	0.24	11.84

Appendix 5. Continued.

Core	Depth (cm)	$\delta^{15}N$	$\delta^{13}C$	%C	%N	C/N
HB2	120	7.0	-21.2	2.38	0.[illegible]	8.58
HB2	130	6.4	-21.8	2.08	0.19	13.11
HB2	140	6.7	-21.8	2.10	0.[illegible]7	9.03
HB2	150	6.6	-21.2	1.44	0.28	5.93
HB2	160	7.3	-21.9	1.58	0.[illegible]3	8.04
HB2	170	6.6	-22.5	1.16	0.09	15.07
HB2	180	7.4	-22.5	1.09	0.[illegible]8	16.20
HB2	190	6.6	-22.4	0.85	0.[illegible]5	6.57
HB2	200	6.8	-22.5	0.57	0.[illegible]3	8.20
HB2	210	7.0	-22.4	0.72	0.[illegible]8	11.19
HB2	220	7.2	-22.2	0.76	0.[illegible]3	6.94
HB2	230	6.6	-22.8	0.56	0.[illegible]8	8.12
HB2	240	6.7	-22.5	0.89	0.[illegible]	17.93
HB2	250	7.5	-22.4	0.77	0.[illegible]	9.33
HB2	252	7.5	-21.3	0.89	0.[illegible]	10.19
HB2	260	6.9	-22.6	0.80	0.[illegible]	14.24
HB2	270	6.9	-22.2	0.75	0.[illegible]	12.01
HB2	280	6.3	-22.9	0.78	0.[illegible]	13.48
HB2	290	7.2	-22.1	0.94	0.[illegible]	8.50
HB2	297	6.5	-22.5	1.21	0.[illegible]	21.60
GB2	0	7.8	-21.0	3.39	0.[illegible]	7.59
GB2	10	7.6	-21.0	2.86	0.[illegible]	11.01
GB2	20	7.5	-21.2	4.23	0.63	7.86
GB2	24	7.2	-21.4	2.87	0.[illegible]	7.49
GB2	34	7.3	-21.3	2.53	0.[illegible]	8.04
GB2	44	7.8	-22.4	1.68	0.[illegible]	7.59
GB2	54	7.7	-21.6	1.10	0.[illegible]	8.96
GB2	64	7.6	-22.1	1.84	0.32	6.64
GB2	74	7.9	-21.9	0.91	0.[illegible]	9.79
GB2	84	7.9	-21.8	0.91	0.[illegible]	14.76
GB2	94	7.8	-21.8	0.68	0.[illegible]	7.09
GB2	104	7.3	-21.9	1.62	0.[illegible]	4.79
GB2	114	7.3	-23.0	1.57	0.24	7.49
GB2	124	7.0	-22.9	1.09	0.22	5.88
GB2	134	7.7	-22.1	0.88	0.[illegible]	5.69
GB2	144	7.8	-22.3	0.73	0.[illegible]	4.74
GB2	154	7.9	-22.2	0.87	0.[illegible]	9.73
GB2	160	8.3	-22.0	0.85	0.[illegible]	9.10
GB2	170	7.6	-22.6	1.16	0.22	6.06
GB2	180	8.3	-22.0	0.69	0.[illegible]	7.78
GB2	190	7.5	-22.5	0.84	0.17	5.64

Appendix 5. Continued.

Core	Depth (cm)	$\delta^{15}N$	$\delta^{13}C$	%C	%N	C/N
GB2	200	7.8	-22.2	0.71	0.18	4.57
GB2	210	8.5	-21.8	0.83	0.09	10.49
GB2	220	8.4	-21.9	0.68	0.11	7.44
GB2	230	7.7	-21.9	0.85	0.10	10.10
GB2	240	7.8	-22.4	0.66	0.10	7.92
GB2	250	7.7	-22.1	0.79	0.10	9.33
GB2	260	8.3	-21.6	0.63	0.11	6.78
GB2	270	8.2	-21.8	0.79	0.11	8.50
GB2	280	8.3	-21.9	0.63	0.11	6.66
GB2	290	8.4	-21.9	0.75	0.09	9.39
GB2	300	7.7	-21.8	0.56	0.09	7.35
GB2	310	7.8	-21.9	0.61	0.09	8.12
GB2	320	7.5	-22.6	0.99	0.09	12.71
ND2	0	6.9	-21.1	1.95	0.33	5.92
ND2	10	7.2	-20.8	1.57	0.35	5.21
ND2	20	7.1	-22.5	0.65	0.09	8.84
ND2	30	6.8	-22.6	0.68	0.08	10.06
ND2	40	6.5	-22.9	0.58	0.07	9.64
ND2	43	6.0	-22.8	0.60	0.08	8.59
ND2	53	6.6	-22.4	0.49	0.10	5.58
ND2	63	6.1	-22.5	0.57	0.08	8.04
ND2	73	6.4	-22.3	0.51	0.09	6.82
ND2	83	7.0	-22.2	0.54	0.08	7.63
ND2	93	6.5	-22.4	0.47	0.09	6.36
ND2	103	6.3	-22.4	0.42	0.10	4.95
ND2	113	7.4	-22.6	0.43	0.07	6.80
ND2	123	7.0	-22.6	0.39	0.07	6.26
ND2	133	6.6	-22.7	0.45	0.07	7.14
ND2	143	6.3	-23.2	0.38	0.04	10.03
ND2	153	7.0	-22.5	0.44	0.07	6.90
ND2	163	7.1	-22.3	0.44	0.07	7.07
ND2	173	7.4	-22.6	0.39	0.05	8.53
ND2	180	7.6	-22.6	0.36	0.05	7.56
ND2	190	7.4	-22.7	0.38	0.05	9.31
ND2	200	7.5	-22.7	0.45	0.06	9.20
ND2	210	7.0	-22.6	0.40	0.06	8.56
ND2	220	6.6	-22.7	0.48	0.06	9.81
ND2	230	7.5	-22.4	0.45	0.06	8.39
ND2	240	7.6	-22.5	0.52	0.07	9.15
ND2	250	7.9	-22.6	0.46	0.06	8.33
ND2	260	7.1	-22.3	0.59	0.07	9.79

Appendix 5. Continued.

Core	Depth (cm)	$\delta^{15}N$	$\delta^{13}C$	%C	%N	C/N
ND2	270	7.3	-22.8	0.45	0.06	8.85
ND2	280	6.3	-23.0	0.54	0.07	9.37
ND2	290	6.3	-23.3	0.55	0.05	11.93
ND2	300	6.9	-23.5	0.80	0.04	21.66
ND2	310	6.3	-24.1	0.76	0.04	24.67
ND2	320	5.7	-24.0	0.63	0.08	9.20
ND2	330	6.0	-22.9	0.51	0.08	7.82
ND2	340	5.8	-22.4	0.58	0.07	9.35
ND2	347	6.1	-21.8	0.49	0.07	7.65
ND2	CC	6.6	-21.9	0.53	0.08	8.06
NS1	0	7.5	-20.8	5.79	1.01	6.71
NS1	10	7.8	-20.7	4.40	1.03	4.98
NS1	30	7.8	-20.6	4.84	0.72	7.82
NS1	40	7.8	-20.3	3.50	0.63	6.50
NS1	50	7.6	-20.4	4.39	0.61	8.25
NS1	60	7.6	-20.7	3.24	0.61	6.15
NS1	70	7.8	-20.6	4.00	0.62	7.57
NS1	80	7.2	-20.6	2.78	0.41	6.88
NS1	90	7.2	-20.6	2.71	0.31	9.76
NS1	100	7.2	-20.6	2.11	0.27	9.09
NS1	110	7.2	-21.0	2.51	0.30	9.66
NS1	120	7.7	-21.3	1.98	0.25	7.97
NS1	130	7.5	-20.7	2.61	0.31	10.22
NS1	140	7.6	-20.5	1.93	0.41	5.08
NS1	150	7.2	-20.4	1.76	0.21	9.98
NS1	160	7.4	-20.5	1.97	0.24	9.74
NS1	170	7.4	-20.2	1.78	0.27	7.69
NS1	180	7.3	-20.9	1.65	0.17	11.69
NS1	190	7.8	-21.1	1.41	0.20	8.30
NS1	200	7.2	-20.6	1.35	0.17	9.46
NS1	210	7.2	-21.3	1.24	0.17	8.55
NS1	220	7.5	-21.0	1.37	0.16	10.05
NS1	225	8.1	-21.0	1.11	0.12	10.91
B11	0	7.5	-20.9	3.35	0.63	6.23
B11	10	7.5	-21.0	3.09	0.43	8.40
B11	20	7.3	-21.1	2.76	0.47	6.80
B11	30	7.2	-21.1	2.58	0.41	7.37
B11	40	7.3	-21.3	3.16	0.44	8.36
B11	50	6.8	-21.3	2.38	0.55	5.05
B11	60	7.4	-21.4	2.86	0.37	8.96

Appendix 5. Continued.

Core	Depth (cm)	$\delta^{15}N$	$\delta^{13}C$	%C	%N	C/N
B11	70	7.5	-21.5	2.37	0.34	8.13
B11	80	7.4	-21.4	2.83	0.34	9.67
B11	90	7.7	-21.4	2.05	0.31	7.82
B11	100	7.4	-21.5	2.39	0.30	9.29
B11	120	7.5	-21.4	2.20	0.31	8.34
B11	140	7.2	-21.6	1.32	0.23	6.84
B11	160	7.2	-21.8	1.21	0.14	10.34
B11	180	7.3	-22.0	0.91	0.11	9.36
B11	200	7.2	-22.0	0.82	0.10	9.51
B11	220	7.4	-21.9	0.86	0.08	11.90
B11	240	7.6	-21.9	0.77	0.09	10.00
B11	260	7.5	-21.9	0.82	0.08	11.40
B11	280	7.5	-21.9	0.73	0.09	9.58
B11	300	7.7	-21.8	0.81	0.09	10.82
B11	320	7.7	-21.6	0.61	0.08	9.56
B11	340	7.6	-21.7	0.71	0.08	10.84
B11	360	7.4	-21.9	0.53	0.07	9.53
B11	380	7.5	-21.8	0.47	0.05	10.63
B11	400	7.3	-21.9	0.46	0.06	9.14
B11	420	7.5	-21.7	0.61	0.07	10.40
B11	440	7.7	-21.6	0.49	0.06	8.90
B11	460	7.5	-21.5	0.54	0.06	10.13
B11	480	7.3	-21.8	0.40	0.05	8.89
B11	500	7.8	-21.7	0.51	0.06	9.83
B11	520	6.8	-21.7	0.47	0.07	7.69
B11	540	6.7	-21.6	0.56	0.08	8.23
B11	555	7.2	-21.9	0.57	0.08	8.24